

EFFECTS OF UTILIZING
CROP RESIDUES
IN WINTER FEEDING SYSTEMS
ON BEEF COW PERFORMANCE,
REPRODUCTIVE EFFICIENCY
AND ECONOMICS

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ABSTRACT

Over 2 years (Year 1, 2009-2010; Year 2, 2010-2011), two separate experiments were conducted to evaluate the effects of winter feeding system (n=3) on beef cow performance, reproductive performance, economics and forage degradability. The three systems (treatments) were grazing pea crop residue (PEA) cv. 'Performance 40-10' (Year 1, TDN = 50.2%, CP = 7.3%; Year 2, TDN = 56.9%, CP = 8.9%) in field paddocks, grazing oat crop residue (OAT) cv. 'Baler' (Year 1, TDN = 59.1%, CP = 2.9%; Year 2, TDN = 66.9%, CP = 5.3%) in field paddocks, and feeding mixed grass-legume hay in drylot pens (DL) (Year 1, TDN = 61.4%; CP = 8.8%; Year 2, TDN = 52.3%, CP = 12.3%). In the first experiment, 90 dry, pregnant Black Angus cows (Year 1, 629 kg \pm 74 kg; Year 2, 665 \pm 69 kg) stratified by body weight (BW) and days pregnant were randomly allocated to 1 of the 3 systems. Cows were allocated feed in the field or pen on a 3 d basis and supplemented oat grain daily at 0.4-0.6% BW depending on environmental conditions. Dry matter intake (DMI) was estimated for each system using the herbage weight disappearance method. Cow BW, body condition score (BCS), and rib and rump fat were measured at start and end of trial and cow BW was corrected for conceptus gain based on calving data.

When data from the first 20 d were pooled over 2 years, initial cow BW was greater ($P < 0.01$) for the DL and OAT cows compared to the PEA cows and final cow BW was different ($P < 0.01$) between all 3 winter feeding systems. The change in BW was also greater ($P < 0.01$) for DL cows compared to cows on the OAT and PEA treatments. Analysis of the first 20 d of Year 1 study period and the total Year 2 study period, showed a significant ($P < 0.01$) year by treatment interaction for final BW and BW change. The differences ($P < 0.01$) in initial BW, final BW and BW change between the first 20 d of Year 1 study period and the total Year 2 study period (20 d)

suggest feed quality, animal preference and weather conditions may cause difficulties when grazing residues in winter grazing systems.

Analysis of the entire trial period in Year 1 (62 d) indicates differences ($P < 0.01$) for final BW and BW change between cows on all three systems. The change in rib and rump fat was also different ($P < 0.01$) between cows in all 3 systems. In Year 2 (20 d), initial BW, final BW and BW change were different ($P < 0.01$) between DL and PEA cows, and between ($P < 0.01$) OAT and PEA cows. No difference ($P > 0.05$) was found for cow rib and rump fat in Year 2 and no difference ($P > 0.05$) was found for BCS in either Year 1 or Year 2 for cows managed in all 3 systems. Differences ($P < 0.05$) were observed for calving rate and calf birth weight between the DL and OAT system cows, but not between ($P > 0.05$) cows managed in the DL and PEA or OAT and PEA systems. Costs per cow per day were \$1.22, \$1.01 and \$2.77 for PEA, OAT and DL systems in Year 1, respectively. In Year 2, cow costs per day were \$1.59, \$1.44 and \$1.84 for PEA, OAT and DL systems, respectively.

In experiment 2, three ruminally cannulated, dry Holstein cows were fed a silage based total mixed ration (TMR) of 22 kg barley silage, 7 kg chopped alfalfa hay and 1 kg energy supplement (DAC-485). *In-situ* degradability was studied to determine the extent of degradation of pea, oat and grass-legume hay collected at start (SOT) and end of test (EOT) in experiment one. Rate of degradation (K_d) of DM was greater ($P < 0.01$) for PEA EOT compared to HAY, OAT SOT and OAT EOT. Dry matter rate of degradation for PEA SOT was greater ($P < 0.05$) compared to OAT SOT and OAT EOT. The effectively degradable fraction of CP was greater ($P = 0.03$) for HAY compared to PEA EOT. The ruminally undegradable fraction of CP was greater ($P = 0.03$) for PEA EOT compared to HAY. Acid detergent fiber rate of degradation (K_d) was greater ($P = 0.01$) for PEA EOT compared to HAY, OAT SOT and OAT EOT. Acid detergent

fiber rate of degradation for PEA SOT was greater ($P < 0.05$) compared to OAT SOT and OAT EOT. No differences ($P > 0.05$) were observed between either OAT SOT and OAT EOT or PEA SOT and PEA EOT for S, D, U, ED or RU suggesting that weathering did not have an effect on the degradability of the forages.

The results of these experiments show that it is possible to maintain cow BW through the winter months in Western Canada by grazing oat crop residues, which have the potential to reduce winter feeding costs.

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LIST OF ABBREVIATIONS

ADF	Acid detergent fiber
ADG	Average daily gain
ADL	Acid detergent lignin
ADIN	Acid detergent insoluble nitrogen
ADIP	Acid detergent insoluble protein
AIA	Acid insoluble ash
AOAC	Association of Official Analytical Chemists
BCS	Body condition score
BW	Body weight
CP	Crude protein
D	Potentially degradable fraction
DE	Digestible energy
DM	Dry matter
DMI	Dry matter intake
EDDM	Effective degradability of dry matter
EDNDF	Effective degradability of neutral detergent fiber
h	Hour
ha	Hectare
IVDMD	<i>In vitro</i> dry matter digestibility
IVOMD	<i>In vitro</i> organic matter digestibility
Kd	Rate of degradation
Kp	Rate of passage
ME	Metabolizable energy
mL	Milliliters
MP	Metabolizable protein
N	Nitrogen
NDF	Neutral detergent fiber
NDIN	Neutral detergent insoluble nitrogen
NDIP	Neutral detergent insoluble protein
NEg	Net energy of gain
NEm	Net energy of maintenance
NPN	Non-protein nitrogen
NSC	Non-structural carbohydrates
RDP	Rumen degradable protein
RUP	Rumen undegradable protein
S	Immediately soluble fraction
SAS	Statistical analysis systems
SD	Standard deviations
T0	Lag time
TDN	Total digestible nutrients
U	Undegradable fraction

1.0 General Introduction

Winter feeding costs are a major contributor to the overall cost of production for cow-calf producers (Taylor 2007; Kaliel and Kotowich 2002; Rasby et al. 1996). Traditionally, these costs are due to feeding cows in drylot pens over the winter period, which includes costs for harvesting, handling and transporting feed and removal of manure (Hitz and Russel 1998; Johnson and Wand 1999; Volesky et al. 2002). Providing feed to pregnant cows during the winter months in western Canada is usually as hay in round bales (Saskatchewan Ministry of Agriculture 2011). Costs per tonne of hay will vary annually but are on average between \$33 and \$44 per tonne (Saskatchewan Ministry of Agriculture 2011). When dealing with the economics associated with cow-calf production, it is important to have a least cost production system in place, however current literature is limited for winter feeding systems for beef cows.

The beef industry suffered financial risk during recent years, which has renewed interest in finding alternative feeding strategies for beef cows. Grazing pregnant beef cows on stockpiled forages, bale grazing, swath grazing or grazing crop residues through the winter months are options to potentially reduce the costs of wintering beef cows. One study reported that cows grazing either stockpiled tall fescue-alfalfa, smooth grass-red clover or corn crop residues may have body weight gain and body condition scores as high or higher than cows wintered on sun-cured hay in drylot pens (Hitz and Russell 1998). Some studies have also suggested that swath grazing can reduce cow costs per day (Karn et al. 2005; McCartney et al. 2004). Swath grazing is when a cereal grain crop is cut at the soft dough stage and left in the field to be grazed in fall or winter. Lately there has been renewed interest in utilizing crop residues (straw and chaff) in beef cow diets because of their potential to reduce winter feed costs (McCartney et al. 2006). Crop residues are the materials left after a crop has been harvested and include straw, leaves,

unthreshed heads, glumes, hulls, and kernels (AAFRD 2008). Since crop residues are a low quality feed, they are only suitable for mature beef cows.

The objectives of this review are to:

1. Examine beef cow nutrient requirements and nutrition in relation to winter feeding practices.
2. To review beef cow performance and reproductive efficiency measurements.
3. To review digestibility of different forages used in winter feeding systems.
4. Evaluate the economics of beef cow wintering systems.

2.0 Literature Review

2.1 Beef cow nutrition in winter feeding systems

Meeting the beef cow's nutritional requirements throughout the winter months is essential to maintain cow performance and reproductive efficiency. If nutrients provided do not meet the cow's requirements, a decrease in production including cow body weight (BW), rib and rump fat and body condition score (BCS) will be observed (NRC 1996). As a result, the cow's reproductive efficiency will also be compromised, potentially causing lower calf birth weights, a decrease in conception rates and an increase in calving interval (Schneider 2004; De Rouen et al. 1994; Karn et al. 2005). It is important when formulating diets to balance beef cow rations for energy, and if energy is limiting in the forage it must be supplemented (NRC 1996). In addition, protein must also be closely monitored and it is often necessary to supplement crude protein in winter feeding systems for beef cows (NRC 1996).

2.2 Energy requirements

Energy requirements for beef cattle at various stages of physiological productivity can be found in NRC (1996) and are dependent on several factors including the season, breed, age, sex, physiological status and activity level of the cattle. There are several definitions of energy available in the literature. It is important that one understands the differences between gross energy, digestible energy, metabolizable energy and net energy when discussing the energy requirements of the beef cow. Gross energy (E) is the net combustible energy or heat released during combustion to carbon dioxide and water (NRC 1996). Digestible energy (DE) is the portion of energy remaining after the fecal energy (FE) has been removed (NRC 1996). Metabolizable energy (ME) accounts for losses in the energy required for metabolism of a feed and is the energy remaining after fecal energy (FE), urinary energy (UE), and gaseous energy (GE) have been removed (NRC 1996). Net energy (NE) is the energy left after the heat increment (HI) has been removed and includes the net energy required for maintenance (NE_m) (Equation 2.3) and the net energy for production or growth (NE_p) (NRC 1996). According to NRC (1996), NE_m is 0.81 Mcal/kg for a dry 636 kg beef cow in 2nd trimester of gestation. Digestible energy can be predicted for different forage and feed types using either Equation 2.1 or 2.2.

Equation 2.1 Penn State grass-legume equation (Adams 1995)

$$\text{Digestible Energy (Mcal kg}^{-1}\text{; DE)} = 0.04409 \times (4.898 + [1.044 - \{0.0119 \times \text{ADF}(\%)\}]) \times 89.796$$

Equation 2.2 Penn State cereal grain equation (Adams 1995)

$$\text{Digestible Energy (Mcal kg}^{-1}\text{; DE)} = 0.04409 \times (4.898 + [0.9265 - \{0.00793 \times \text{ADF}(\%)\}]) \\ \times 89.796$$

Equation 2.3 Net Energy for maintenance (NRC 1996)

$$\text{NE}_m = \text{SBW}^{0.75} * [\{0.077 * \text{BE} * \text{L} * (0.8 + ((\text{CS} - 1)0.05))\}] + 0.0007(20 - \text{T}_p)]$$

Where NE_m is net energy for maintenance, SBW is shrunk body weight, BE is breed effect on NE_m requirement, L is lactation effect on NE_m requirement (1 if dry), CS is condition score (9 point scale), T_p is previous average monthly temperature ($^{\circ}\text{C}$) (NRC 1996).

2.2.1 Factors affecting energy requirements

For pregnant beef cows, energy requirements will vary depending on breed, season, age and sex, physiological status including trimester of pregnancy and stage of lactation, and activity level (NRC 1996). NRC (1996) reports nutrient requirements including total digestible nutrients (TDN), DE, crude protein (CP) and minerals based on these factors that will change the cows' requirements. The following sections will explain how breed, season, age and sex, and physiological status affect the cows' energy requirements.

2.2.1.1 Breed

Several studies have concluded that there is variation in the energy requirements between different breeds of cattle. According to Garrett (1971), Holstein steers require 23 percent more energy than Hereford steers at the same stage of production. Jenkins and Ferrell (1984) and Ferrell and Jenkins (1985) found that Simmental cattle required 19 percent more energy than

Herefords at maintenance. Other studies report that *Bos indicus* breeds require 10 percent less energy for maintenance than *Bos taurus* breeds and 5 percent less for *Bos indicus* x *Bos taurus* crosses (Vercoe 1970; Vercoe and Frisch 1974; Patle and Mudgal 1975; Frisch and Vercoe 1976; Frisch and Vercoe 1977; Frisch and Vercoe 1982; van der Merwe and van Rooyen 1980; Carstens et al. 1989).

2.2.1.2 Season

The effect of season on energy requirements is related to temperature and environmental factors including precipitation and wind speed. Birkelo et al. (1989) reported that season itself has an effect on Fasting Heat Production (FHP), with lower FHP during fall, winter and spring than during summer. The thermoneutral zone (TNZ) is the range where an animal's heat dissipation to the external environment is independent of temperature and is determined by feed intake and efficiency (NRC 1996). When the ambient temperature is outside of this range, either above the upper critical temperature (UCT) or below the lower critical temperature (LCT), productivity decreases (NRC 1996). Above the UCT, productivity decreases because of reduced feed intake and increased energy required to dissipate excess heat (NRC 1996). Below the LCT, animal metabolism must increase to maintain body temperature, which increases the animal's energy requirement (NRC 1996). For a mature beef cow consuming a maintenance diet, the LCT is -21°C (Webster 1974). NRC (1996) concluded that the required NE_m of cattle is adapted to the thermal environment as in the following equation:

Equation 2.4 NE_m adapted to the thermal environment (NRC 1996)

$$\text{NE}_m = (0.0007 * (20 - T_p)) + 0.077 \text{ Mcal/SBW}^{0.75}$$

Where T_p is the ambient temperature in degrees celcius. The equation indicates that for every degree that the previous ambient temperature differed from 20°C, the NE_m requirement of cattle changes by $0.0007 \text{ Mcal/BW}^{0.75}$ (NRC 1996).

2.2.1.3 Age and sex

The relationship between age and maintenance requirements is undetermined as there are arguments to support both sides of whether or not energy for maintenance decreases with age. Several studies report that age has little influence on maintenance requirements of cattle, other than those factors associated with weight (Blaxter et al. 1966; Blaxter and Wainman 1966; Taylor et al. 1981; Birkelo et al. 1989; Vermorel et al. 1980). Conversely, it is generally accepted that maintenance requirement declines with age per unit of size for cattle and sheep (Blaxter 1962; Graham et al. 1974). Graham et al. (1974) reported that maintenance decreased exponentially at 8 percent per year, while Corbett et al. (1985) reported that maintenance decreases 3 percent per year. The Commonwealth Scientific and Industrial Research Organization (CSIRO) (1990) adopted the principle that maintenance decreases 3 percent per year until 84 percent of initial values are reported.

Gender is usually thought to have an affect on the energy requirements of animals. Studies show that steers and heifers of the same breed have similar fasting heat production (Garrett 1970; Garrett 1980; CSIRO 1990; ARC 1980). However, differences were found when comparing bulls to heifers. Ferrell and Jenkins (1985) reported similar FHP for Hereford bulls and heifers, but a 9 percent increase for Simmental bulls compared to Simmental heifers. Webster et al. (1977) reported a 20 percent increase for Hereford x Friesian bulls compared to steers of the same breed cross. ARC (1980) and CSIRO (1990) both concluded that bulls have 15 percent higher maintenance requirements than steers or heifers of the same breed.

2.2.1.4 Physiological status

The physiological state of cattle has an effect on energy requirements, such that energy requirements will increase during growth, pregnancy and lactation. Indirect evidence shows that maintenance requirements of cows increases during gestation (Brody 1945; Kleiber 1961; Ferrell and Reynolds 1985) and is thought to be because of the productive processes of pregnancy. Several studies report that maintenance requirements of lactating cows are greater than those of nonlactating cows. On average, this difference has been found to be 20 percent higher for lactating versus nonlactating cows (Moe et al. 1970; Flatt et al. 1969; Neville and McCullough 1969; Neville 1974; Patle and Mudgal 1975; Patle and Mudgal 1977; Ferrell and Jenkins 1985; Ferrell and Jenkins 1987).

2.2.1.5 Activity

The amount of activity that an animal performs can have a significant impact on the amount of energy that it requires for maintenance. An animal grazing pasture will require more energy than an animal fed in a drylot pen due to the energy required for walking to find food (McCartney et al. 2004). Energy expenditure for grazing cattle will be affected by several factors including pasture quality, availability of herbage, topography, location of water source and weather (NRC 1996). CSIRO (1990) suggests that energy requirements for cattle grazing in ideal conditions are 10 to 20 percent greater than cattle fed in drylot pens, while cattle grazing in hilly pastures and far distances to water can require up to 50 percent more energy than those in drylot pens.

2.3 Prediction of feed intake

It is important to be able to estimate the feed intake of beef cattle in order to predict their rate of gain and nutrient requirements. Estimation of dry matter intake of ruminants includes several factors and is not completely understood. Several techniques are available for predicting forage dry matter intake (DMI) of grazing animals and include the use of markers in the feed, observation of ingestive behaviour, and herbage mass disappearance.

2.3.1 Factors affecting feed intake

Factors affecting DMI of ruminants include the animal's size and physiological state, environmental conditions, management, and nutritional qualities of the feed. Body composition, specifically percentage of body fat, is commonly considered to affect DMI of beef cattle (NRC 1996). Fox et al. (1988) found that for each 1 percent increase over 21.3 to 31.5 percent body fat, DMI decreases by 2.7 percent. Frame size has also been found to have an effect on feed intake and Fox et al. (1988) suggested that prediction equations adjust frame sizes to an equivalent mature weight. Relative to smaller framed, British-breed cattle, intake predictions should be increased 8 percent for Holsteins and 4 percent for Holstein x British breed crosses (Fox et al. 1988). Dry matter intake is greatly altered by the animal's physiological state such as lactation. Dry matter intake has been reported to have an average increase of 30 percent during lactation (Minson 1990). A decrease in DMI has also been found late into pregnancy, such that DMI decreases by 2 percent per week during the last month of pregnancy (NRC 1996).

Environmental factors that have been found to affect DMI include ambient temperature, wind and precipitation, and season or photoperiod. As the ambient temperature falls below the thermoneutral zone, feed intake generally increases (Kennedy et al. 1986; Minton 1986; Young

1986). This observation may vary with acclimation and nutritional quality of the diet (Young 1986). Adams (1987) found that during acute cold stress, forage DMI may decrease up to 47 percent due to decreased grazing time. Photoperiod has been found to have an effect on DMI such that voluntary dry matter intake increases by 0.6 to 1.5 percent per hour increase in day length (NRC 1996).

Dry matter intake has also been found to be affected by the quantity of forage available to grazing animals. Rayburn (1986) concluded that forage intake for grazing cattle was maximized when forage availability was approximately 2,250 kg DM per hectare.

2.3.2 Prediction equations

Several equations have been developed to predict the feed intake of beef cattle. Intake prediction equations can be adjusted for specific production systems by using inputs for animal requirements, environment, forage quality and nutrient metabolism (Fox et al. 2004). NRC (1996) predicts DMI as a function of dietary energy concentration and shrunk body weight (SBW) adjusted for frame size or sex. Mertens (1983) developed an equation to predict DMI for cattle consuming forages as a function of neutral detergent fiber (NDF).

Undi et al. (2008) compared three techniques for their ability to estimate DMI for grazing beef cattle. The first technique used grazing cages and forage inside and outside the cages was clipped from 0.25 m² quadrants. The second technique was a marker technique and used n-alkane controlled release capsules to measure DMI of grazing cattle individually. The last two techniques used prediction equations to estimate DMI. One was the equation developed by Minson (1990) which uses body weight (BW) and average daily gain (ADG), while the other was the equation from NRC (1996), which uses dietary net energy concentration and SBW. The

cage technique gave estimates of DMI with the largest variation ranging from 0.3 - 15.2% BW, while the n-alkane marker technique estimated that DMI ranged from 0.6 - 4.5% body weight. The prediction equations gave the strongest correlation ($r = 0.30$; $P = 0.001$) in DMI estimates. Results from this study suggest that prediction equations provide the best estimates of DMI because of their inclusion of BW (Undi et al. 2008).

2.3.3 Estimation of total apparent intake

There are several techniques to estimate DMI and these include both direct and indirect measurements. Direct measurements of DMI can be made by weighing animals or observing grazing behaviour (Burns et al. 1994). When weighing animals, adjustments must be made for fecal, urinary and respiratory losses, water consumption and non-forage consumption (Minson 1990; Gordon 1995). Intake of fresh herbage must also be adjusted for dry matter intake by moisture determination from clipped herbage at the same time and location of grazing in order to decrease error (Minson 1990). Determining forage intake by observation requires estimation of time spent grazing, mass per bite and biting rate (Minson 1990). These estimates can be gathered more accurately using equipment such as grazing and GPS collars (Minson 1990). A difficulty in collecting accurate estimates can be caused by differing stage of plant growth and diverse plant species, which will cause a selective grazing response (Holechek et al. 1982).

The disappearance method for forages is another way to predict DMI, and is determined by calculating the difference between pre- and post- grazing weight of forages (Volesky et al. 2002). A fixed proportion of the total grazing area is clipped pre- and post-grazing to determine herbage mass (Meijs 1981). Since labour, time and costs are high for this type of forage DMI estimation, indirect measurement is more commonly used.

Indirect measurement commonly uses ratios of indigestible markers in the feed compared to the fecal material to determine the digestible forage. Indigestible markers include those added to the feed such as chromium or ytterbium or those that may be naturally occurring in the forage such as lignin (Morse et al. 1992). Once digestibility is calculated and fecal output is determined, the fecal amount is divided by the percent of indigestible forage to calculate intake (Volesky et al. 2002). External markers added to the feed can be used to estimate fecal output using the marker's recovery rate in the following equation;

$$\text{Fecal output} = \text{Dose of external marker} \times (\text{marker concentration in feces})^{-1} \times (\text{recovery rate})$$

(Romanczak 2005)

Recovery rate of the marker is calculated by dividing the total weight of the marker in feces by the total weight of the marker in the feed (Romanczak 2005). Examples of internal markers occurring naturally in the forage are lignin, acid insoluble ash (AIA), chromogen and alkanes (Morse et al. 1992; Wilson et al. 1971; Minson 1990; Mayes et al. 1986). In a review, Wilson et al. (1971) found AIA to determine digestibility more accurately than lignin. External and internal markers have been successfully used to estimate forage intake, however researchers must be aware of potential errors (Volesky et al. 2002; Minson 1990).

2.4 Measuring beef cow performance

In order to evaluate the effectiveness and impact of winter feeding systems, beef cow performance must be measured. Beef cow performance relates to the animal's overall energy balance and can be divided into growth, lactation and reproduction. For pregnant beef cows at their mature weight, the main objective is to maintain weight with no net loss or gain outside of fetal growth (NRC 1996). Beef cow performance can be measured using several different

techniques, including measuring body weight, body fat composition using ultrasound and body condition scoring (BCS) (Corbett 1978; Schröder and Staufenbiel 2006; Lowman et al. 1976).

2.4.1 Body weight

Body weight changes are commonly measured to determine beef cow performance during research trials. There are errors associated with this measurement such as gut fill and water retention (Corbett 1978). These errors can be minimized by using several techniques including averaging the weights of cattle taken over two consecutive days, withholding feed or water for 24 h to achieve shrunk body weight, and reducing stress during weighing (Cook and Stubbendieck 1986). Silvey and Haydock (1978) found that it was possible to more accurately measure the body weight of pregnant cows by adjusting their weight for conceptus gain. Body weight may be an easy measurement, however it must be used in addition to measurements for body fat composition and body condition score (BCS) because it does not take into account the frame size of the animal (Corbett 1978).

2.4.2 Body fat composition

Ultrasound assessment has been used in the animal agriculture industry for many years and provides accurate measurements of body fat. Ultrasound measurement is a non-invasive technique (Schröder and Staufenbiel 2006) and is easily performed by a trained technician (Perkins et al. 1992). Electrical pulses are emitted as high frequency sound waves, which are then converted into images representing the density of the tissue being examined (Houghton and Turlington 1992). Common measurements determine the back fat thickness to the nearest 1 mm at the rump and between the 12th and 13th ribs (Schröder and Staufenbiel 2006). Ultrasonography

is considered to be a more accurate tool than BCS, although it is more expensive and requires more training to perform.

2.4.3 Body condition

Body condition score (BCS) is estimated by visual appearance and physical palpation of body fat reserves at several locations on the body including the lumbar process and tail head region (Domecq et al. 1995). Body condition score is a subjective evaluation where the animal is given a score of 1 to 5 (Canadian scale) where 1 is emaciated and 5 is obese (Lowman et al. 1976). In the United States a 9 point scale is used (Marlowe et al. 1962). Estimation of BCS can contain error because of the technician's ability to perform accurate estimates over a period of time. Lowman et al. (1976) considers BCS an important economic parameter in cow-calf operations because cows with adequate condition in the fall will have reduced feed costs through the winter months. Body condition score can be a useful tool alone in determining the energy reserves of an animal, but because of its subjective nature it is recommended to be used in combination with other techniques (Bullock et al. 1991; Waldron et al. 2006). According to Domecq et al. (1995) BCS is a valid measurement because it has a strong correlation with quantitative measurements taken by ultrasound.

2.5 Beef cow reproductive performance

Nutritional status plays a large role in the reproductive success of animals through physiological mechanisms. Through evolution, natural selection has acted on genetic variation allowing the survival of the best adapted individuals for energy intake, storage and expenditure, allowing animals to survive to reproductive maturity (Schneider 2004). In most species,

reproductive activity occurs when energy availability is abundant, rather than when it is scarce. Energy status will affect fertility, reproductive development, embryo survival and conception rate (Schneider 2004; De Rouen et al. 1994). Low fertility is multifactorial and includes genetics, nutrition, reproductive management, disease control and welfare (Schneider 2004). This section will focus on how nutritional status plays a role in reproductive efficiency.

The objectives of many studies interested in feeding low quality feeds to pregnant beef cows over the winter period, have included the concern of how low quality diets may affect calving performance and subsequent rebreeding (Karn et al. 2005). Evidence is available to support that low pre-calving energy levels can be detrimental to subsequent rebreeding because cows with a low BCS ($BCS < 2$) at calving will require a longer period to return to estrus (Dunn et al. 1969; Bellows and Short 1978). DeRouen et al. (1994) found that cows with higher BCS at calving had shorter pregnancy intervals and higher pregnancy rates. Pregnancy interval was increased by 10 to 18 d ($P < 0.05$) for cows with a BCS of 4 compared to those with a $BCS \geq 5$ (scale 1-9) at time of calving (De Rouen et al. 1994). Cows with a BCS of 4 or 5 were found to have lower ($P < 0.05$) pregnancy rates of 64.9% and 71.4% respectively, while cows with a BCS of 6 or 7 had pregnancy rates of 87.0% and 90.7% respectively (De Rouen et al. 1994).

Another reproductive aspect that studies have compared is calving rates between cows fed low quality forages and those fed high quality hay in drylot pens. Anderson et al. (2005) found that calving rate did not differ between treatment groups, either cows grazing cornstalks or control groups fed mixed hay. In this study, all cows calved at or near a body condition score (BCS) of 5 (scale of 1-9) (Anderson et al. 2005). Larson et al. (2009) studied the effects of protein deficiency in winter grazing systems and the effect on late gestation nutrition of the cow on the unborn fetus. The study provided evidence that dam nutrition does affect the calf birth

body weight (BW) and early calf BW gain, which in turn caused lower weights at weaning and slaughter (Larson et al. 2009). From this, it can be concluded that the cow's protein intake will affect the growth of offspring all the way through to the feedlot. Larson et al. (2009) found that protein supplementation did not affect postpartum pregnancy rates, while Engel et al. (2008) found that protein supplementation in late gestation improved pregnancy rates in heifers. Thus, it is important to monitor protein levels in the forage fed to the dam and supplement if necessary.

During pregnancy, energy status must be adequate to maintain the pregnancy and ensure development of the growing fetus. If the energy status of the cow is not adequate during pregnancy, subsequent postpartum reproduction will be negatively affected (Whitman 1975; Lalman et al., 1997). Cows maintained on an increasing plane of nutrition during the prepartum period have a shorter interval to first ovulation than those on a decreasing plane of nutrition (Perry et al. 1991; Randel 1990). If energy is restricted during the prepartum period, the cow's BCS will be low at calving which may cause difficulties during calving and decrease pregnancy rates (Perry et al. 1991). The postpartum anestrus period will be prolonged, increasing the calving interval and resulting in a lower percentage of cows in estrus during the breeding season (Perry et al. 1991).

At parturition, the negative feedback on the reproductive axis is removed because of the drop in estradiol concentrations (Hess et al. 2005). Consequently, both LH and FSH levels rise, increasing the activity of GnRH pulses, developing ovarian follicles and selecting a dominant follicle for ovulation (Hess et al. 2005). Using beef cows as an example, if they are undernourished, return to ovulation can be suppressed because levels of GnRH will be inadequate (Hess et al. 2005). Body condition at calving and subsequent feeding level are

interrelated in terms of their influence on the interval to first post-partum estrus (Ciccioli et al. 2003). For example, thin cows on a low ME intake compared with those on a high intake had a longer calving interval, while fat cows fed a low or high ME intake had an insignificant difference in return to estrus (Wright et al. 1992, Robinson et al. 1996).

In high-yielding dairy cows, there is a high energy deficit during the first 2 to 3 weeks postpartum, which is closely correlated to the period of time for return to estrus (Roche 2006). After giving birth, the uterus must recover before the female returns to estrus and is capable of becoming pregnant again. It can take 30-40 d for cows to return to normal size post-calving, although it may take up to 60 d for the endometrium to accept a pregnancy and be capable of embryonic development (Roche 2006). Prostaglandin (PG) F_{2α} remains elevated for the first few days after birth, promoting contractions of the uterus and therefore reducing occurrence of retained placenta. Uterine problems may also effect DMI of cows and increase stress resulting in high cortisol secretion (Roche 2006).

Independent of dietary energy intake, lipid supplementation has been found to enhance reproductive function in beef cows (Wehrman et al. 1991). Intake of dietary fat has positive effects on ovarian function and metabolism, especially when supplemented during late gestation. Hess et al. (2002) reported that prepartum nutritional inadequacy normally has negative impacts on reproduction, but if fat is supplemented during late gestation these impacts can be reduced, including postpartum return to estrus, conception, and maintenance of pregnancy. Since prepartum nutrition is very important for subsequent postpartum reproduction, it is accepted that cows receiving a high energy ration prior to parturition will return to estrus sooner following calving than cows that received supplementation after parturition (Hess et al. 2002). Lalman et al. (2000) also found that it is difficult to reverse the negative effects due to inadequate nutrition

prior to parturition by increasing the cow's plane of nutrition postpartum. In contrast, some studies have reported no difference in conception rates or length of time to return to estrus with prepartum fat supplementation (Alexander et al., 2002; Small et al., 2004).

Lammoglia et al. (1999) found that prepartum supplementation with linoleic acid has benefits for the calf as well. Improvement in calf survival was found and was suggested to be a result of an increase in brown adipose tissue, which is essential for thermogenesis in the newborn calf. From this study, it can be seen that the metabolic pathways which affect the ovarian and uterine environments are also altered with fat supplementation. Mattos et al. (2000) considers that there are several mechanisms through which fat supplementation affects reproduction, including corpus luteum (CL) function, LH secretion, synthesis and inhibition of prostaglandins, gene expression and steroidogenesis. During the preantral stage of follicle development, changes in endocrine profiles may impact future reproductive success (Bader et al. 2005).

2.6 Feedstuffs used in winter feeding systems

In western Canada, beef cows are traditionally fed preserved hay bales of preserved perennial forages during the winter months. In recent years the costs of providing feed to cattle during the winter have been increasing, and producers have been looking for alternative ways to feed their beef cattle (Volesky et al. 2002).

2.6.1 Extending the grazing season

In recent years, cow-calf producers have been looking into ways of extending the grazing season in order to reduce winter feeding costs. Extending the grazing season reduces costs associated with labor, baling and hauling feed, infrastructure, manure handling and equipment

that are required when wintering cows in traditional drylot systems (Baron et al. 2006; Hitz and Russel 1998; Johnson and Wand 1999). Extensive wintering systems that will be discussed include stockpiled forage grazing, swath grazing, bale grazing, and grazing crop residues from cereal grain and pulses.

2.6.1.1 Stockpiled forage grazing

One method that producers use to extend the grazing season into the fall and winter is grazing cattle on stockpiled forages. Stockpiled forages are pastures and hay fields that are left for after forage growth has stopped (MAFRI 2008; Riesterer et al. 2000). Stockpiled grass has adequate nutritional quality for mature, dry beef cows from October to December, while stockpiled alfalfa has adequate nutritional quality until late November or when leaves shed (MAFRI 2008). To produce high quality stockpiled forage, the field must be hayed in mid-summer and allowed to regrow for fall or winter grazing (MAFRI 2008). This is because the forage will be of better quality before it reaches maturity. Species selected for stockpiled grazing need to regrow rapidly following mid-summer harvest and maintain high quality following fall frost (AAFRD 2008b). Cherney and Kalenback (2003) reported that cool-season grasses are able to maintain forage quality into the fall and winter better than warm-season grasses because they are adapted to lower temperatures. Grazing stockpiled forages may reduce winter feeding costs for cow-calf producers, but species selection and forage quality need to be considered to meet the animal's nutritional requirements.

2.6.1.2 Swath grazing

Swath grazing is a management practice used to reduce costs associated with feeding cows in drylot pens by increasing the length of the grazing season (AAFRD 2004). Swath grazing is when a cereal grain crop is cut at the soft dough stage and left in the field to be grazed in the winter (AAFRD 2004). Annual crops have been used to lengthen the grazing season during years when perennial pasture is not available. Spring seeded cereals such as barley, oat, triticale and rye are swathed at the mid-dough stage of maturity to prevent the seed from ripening and thus maximizing the nutritional quality of the plant for cattle consumption (McCartney et al. 2008). Lardner (2002) reported that legumes such as peas along with barley can also lengthen the grazing season.

Cattle may be able to obtain all or a portion of their nutritional requirements from swath grazing. Kelln et al.(2011) found that cows were able to maintain BW while swath grazing during the winter for the last 2 yrs of a 3 yr trial. Variation in cow performance was attributed to naive cows in the first yr, variation in winter weather patterns and forage nutrient density (Kelln et al. 2011). During the winter months, the largest issue involved in swath grazing is that the feed accessibility is decreased by icing of the swaths (AAFRD 2004; Kelln et al. 2011). During periods of low temperature, many studies suggest that providing grain as an energy supplement will allow cows to maintain body weight (Karn et al. 2005; Anderson et al. 2005; Kelln et al. 2011).

May et al. (2007) evaluated cool and warm season annual cereal species in fall and winter swath grazing systems for adaptation, quality and dry matter production. Pearl millet, sorghum-sudangrass and corn were determined to be unsuitable for swath grazing in Saskatchewan due to low and variable yields in response to changing environmental conditions (May et al. 2007).

Golden German foxtail millet was found to produce a higher yield than oat and barley with high precipitation and temperature, however under very cool conditions production was less (May et al. 2007).

When considering whether or not to swath graze cattle, it is important to know that it will be necessary to limit the cows' access to the swaths (Karn et al. 2005) to prevent wastage. This is most commonly done with the use of electric fences, which are affordable and easy to assemble. When selecting a field for swath grazing, other management factors that need to be considered are the ability to monitor the condition of cattle (McCartney et al. 2004), water availability and shelter from the wind.

2.6.1.3 Bale grazing

Bale grazing is another extensive management system used to extend the grazing season into the winter months. Forage is cut and baled and moved to a location where cattle will be winter managed in field for grazing (MAFRI 2008b). Access to bales is commonly restricted using portable electric fencing. Bale grazing has been found to be less expensive than traditional drylot systems, even after the costs associated with labour, and baling and hauling feed were included (McCartney et al. 2004; Kelln et al. 2011). Lardner (2005) found that beef cows managed by bale grazing or fed processed hay in the field had similar performance to cows fed in a drylot system. Kelln et al. (2011) found that bale grazed barley hay through the winter was sufficient to meet the cows' maintenance requirements with little or no BW change and no negative effect on reproductive efficiency.

Jungnitsch (2008) studied the effects of spreading manure on pasture compared to pasture winter feeding systems on soil and residual nutrients and future forage growth. Better

capture and recycling of nutrients in feed, bedding and urine was found for cattle managed on the pasture winter feeding systems compared to feeding in a drylot pen and spreading manure on pasture (Jungnitsch 2008). Forage growth was found to be uneven where cattle were fed, especially on the bale grazing treatment where bales were placed and forage growth was more even on the manure treatment (Jungnitsch 2008). This study suggests that bale grazing may improve forage yield and quality of pastures, however there are limitations including uneven forage growth.

2.6.1.4 Crop residue grazing

Crop residues are the materials left after a crop has been harvested and include straw, leaves, unthreshed heads, glumes, hulls, and kernels (AAFRD 2008). Since they are a low quality feed, crop residues are only suitable for mature beef cows (McCartney et al. 2006; AAFRD 2008). Feeding crop residues has both advantages and disadvantages, which will be discussed further.

The main advantage of feeding crop residues is the reduction in feeding costs (McCartney et al. 2006). The decreased costs are associated with being able to graze residues from an annual crop which a producer has already grown, and therefore should require no additional cost to produce the feed (SMA 2012). The most economical method of utilizing crop residues if possible is to pile the residues after combining on the field where cows can be moved to graze. Grazing cows on crop residue piles reduces the costs associated with transporting feed from the field to the drylot location (AAFRD 2008). In drylot pens, crop residues may be mixed with other feeds to reduce costs by extending feed resources, while still meeting the cows' nutrient requirements (AAFRD 2008).

Another advantage is the manure nutrients deposited in the field from grazing cattle since the animals are spreading nutrients in manure and urine, and these nutrients are being distributed back onto the site for the subsequent crop (Kelln et al. 2011). There is also the reduced cost associated with pen cleaning and spreading the manure on neighbouring fields (Kelln et al. 2011). Cows are able to graze different types of crop residue, including annual cereals, legumes and oilseed crops, which allows producers to rotate their crops and still be able to winter graze their cows.

A disadvantage associated with grazing crop residues, is the initial start up cost for purchasing equipment to bale, pile or bunch the chaff and straw (SMA 2012). There are several different options, depending on the type of combine used and whether or not chaff will be piled or baled. Some combines will separate the straw from the chaff, while others release the chaff and straw together. If the chaff is separated from the straw, it may be collected in a 'chaff box' or the 'Redekop chaff blower and wagon' behind the combine and dropped in piles (SMA 2012). If the chaff and straw are combined, the 'Whole Buncher®' or the 'Redekop MAV and wagon' may be used to collect and pile the crop residue (SMA 2012). Each piece of equipment has an initial cost, which may be discouraging to producers interested in starting crop residue grazing.

Another disadvantage is if the crop residue cannot be grazed in the field, the cost of transporting chaff bales to the location where cows will be fed for the winter can be quite costly (AAFRD 2008). This may be true for livestock producers who only have beef cattle and do not grow crops. Other costs that need to be considered include provision of water in the winter grazing system, fencing and portable windbreaks (AAFRD 2008).

Since crop residues are typically a low quality feed (low energy and protein), it is important to provide supplements to meet the cows' nutritional needs (Kelln et al. 2011; Van De

Kerckhove et al. 2011). Another important consideration is that quality will vary depending on the type of crop, maturity, and harvesting procedure (McCartney et al. 2006), which makes it important to test the feed. Finally if crop residues are available for beef cows to winter graze, the overall costs of production can be reduced (McCartney et al. 2006; AAFRD 2008). This may encourage producers to consider integrated cropping and livestock enterprises in order to reduce production costs rather focusing on specialized production.

2.6.1.5 Feed wastage

Feed waste can be a concern in winter grazing systems because it is difficult to prevent animals from trampling, urinating and defecating on the feed or using it as bedding (Bell and Martz 1976; Mader et al., 1999). Several studies have found that it is difficult to measure feed wastage (Brasche and Russell 1998; Buskirk et al., 2003) and many factors are involved in the amount of feed wasted (Yaremcio 2009). Kallenbach (2000) found that up to 40 percent of a large round bale was wasted when it was left unprotected by physical restraints to reduce access. When bale rings, electric fence or fence line bunks were used, feed waste was reduced to 6, 14 and 6 percent, respectively (Kallenbach 2000). Jungnitsch (2008) found that when a 40 percent straw, 60 percent hay ration was fed using a bale processor on field during the winter, 20 percent feed waste was measured. Straw made up 77 percent of this feed wastage, which suggests that feed waste can be affected by diet preference (Jungnitsch 2008).

Yaremcio (2009) measured feed waste during the winter for mixed hay supplied using a bale unroller or bale processor, and cereal silage fed as high moisture round bale silage or chopped pit silage. Waste was found to be 12.9, 19.2, 23.2, and 26.8 percent, respectively. When

hay or either type of silage was fed into portable bunk feeders, feed waste was 0 percent (Yaremicio 2009).

2.6.2 Limitations of low quality forages

Strategies used to extend the grazing season reduce winter feeding costs by supplying nutrients to the cattle using low quality forages that are low in protein and high in fiber (NRC 1996). Nutritional composition of straw and chaff is important when formulating rations using crop residues, to ensure adequate supply of nutrients or avoid feeding nutrients in excess (McCartney et al. 2006). Straw has limited rumen degradability because it is highly lignified from selection for lodging resistance for grain production (McCartney et al. 2006). The proportion of plant parts contributes to the overall degradability, such that leaves have the highest degradability, followed by chaff, nodes and internodes (Ramanzin et al. 1986). It has also been suggested that plant height also impacts forage degradability since taller plants will have proportionally less leaf area and more stem, making them less digestible than shorter plants which will have a higher leaf area to stem ratio (Capper 1988). By genetically selecting for shorter or dwarf type cultivars it is possible to increase the quality of the straw-chaff without compromising grain production (Capper 1988).

Before allowing cows to graze crop residues, the feed needs to be tested for quality and potential presence of mold levels that may be detrimental to animal health. Residues should be tested for levels of crude protein (CP), neutral detergent fiber (NDF) and acid detergent fiber (ADF) and energy content should be determined (McCartney et al. 2006). Acid detergent fiber (ADF) values are often used to estimate the energy content of straw based diets. If energy or protein requirements cannot be met by the crop residues alone, supplementation should be

considered. Energy supplements include cereal grains (barley, oat, etc.), legumes, hay, silage and distillers' grains with solubles (DGS). Protein supplements include canola meal or alfalfa hay added to the diet. Literature covering beef cattle energy requirements such as NRC (1996) is a good source to start at when determining the energy required in the diets for cattle. There are several methods to predict dietary energy or total digestible nutrients (TDN) available in the feed. The first method is the Pennsylvania State equation which predicts percent total digestible nutrients (TDN) based on acid detergent fiber (ADF) (Equation 2.5) (Adams 1995).

Equation 2.5 TDN (Adams 1995)

$$\text{TDN} = 4.898 + \{89.796 * [1.0876 - (0.0127 * \text{ADF})]\}$$

where ADF is expressed on a DM basis. The second method calculates TDN according to Weiss et al. (1992) (Equation 2.6).

Equation 2.6 TDN (Weiss et al. 1992)

$$\begin{aligned} \text{TDN} = & \{0.98 * (1000 - \{(\text{NDF} * 10) - (\text{CP} * \text{NDFIP} / 10) + [0.7 * (\text{CP} * \text{ADFIP} / 10)]\} - (\text{CP} * 10) - \\ & (\text{ash} * 10) + [0.7 * (\text{CP} * \text{ADFIP} / 10)] - (\text{EE} * 10)\} + [-0.0012 * (\text{CP} * \text{ADFIP} / 10)]^2 * (\text{CP} * 10) + 2.25 * \\ & [(\text{EE} * 10) - 10] + 0.75 * \{(\text{ADL} * 10) - (\text{CP} * \text{NDFIP} / 10) + [0.7 * (\text{CP} * \text{ADFIP} / 10)]\} - \\ & (\text{ADL} * \text{NDF} / 10)\} * [1 - ((\text{ADL} * \text{NDF} / 10) / \{(\text{NDF} * 10) - (\text{CP} * \text{NDFIP} / 10) + [0.7 * \\ & (\text{CP} * \text{ADFIP} / 10)]\})^{(0.667)}] - 70\} / 10 \end{aligned}$$

where neutral detergent fiber (NDF), acid detergent fiber (ADF), crude protein (CP), ether extract (EE), and ash are expressed as dry matter (DM). Neutral detergent fiber insoluble protein (NDFIP) and acid detergent fiber insoluble protein (ADFIP) are expressed as percent of CP; and acid detergent lignin (ADL) was expressed as acid detergent fiber.

2.6.3 Supplementing beef cow rations

The purpose of supplementation is to meet the animal's nutrient requirements during periods of nutritional deficiency. These requirements may be for maintenance, production and reproduction (NRC 1996). Nutrient deficiencies can occur in several forms, either energy, protein, or mineral (NRC 1996; Weisenburger and Mathison 1977; Katchener 1980).

When feeding low quality forages, the main nutrient that may be deficient and should be considered is energy (NRC 1996). In order to maintain cows in good body condition, their energy requirements must be met during winter feeding. Low quality forages are low in energy because they consist of mature plant parts with high fiber content and high levels of indigestible lignin (McCartney et al. 2006). In many cases, the ruminant cannot consume enough of these low quality feeds to meet daily energy requirements due to limited gut fill capacity (Lehman 1941; Campling 1970; Forbes 1995). Stretch receptors in the rumen are activated when the rumen is full and these receptors send signals to the ventromedial hypothalamus of the brain that satiety has been reached and the animal cannot consume anymore feed (Baile et al. 1968, Wyrwicka et al. 1960).

Energy supplements commonly used are hay or silage, but if feed must be purchased, cereal grains such as oats, barley, wheat and sorghum can be used (Siebert and Hunter 1982). As levels of concentrates in the diet are increased and forage consumption is decreased, many factors that control the fermentation system within ruminants will be altered. Increasing concentrate feeds high in nonstructural carbohydrates (NSC) reduces the ability of cell wall constituents to be fermented (Bowman et al. 2004; Olson et al. 1999; Sanson et al. 1990). Rumen microflora composition is altered by a decrease in rumen pH (Hiltner and Dehority 1983) and this can result in reduced DMI. Bowman and Sanson (2000) termed this as the substitution

effect. The amount of concentrate feeds used to substitute forage should be considered on a physiological basis.

Protein is the other nutrient to be considered as being deficient when low quality forages are being grazed (NRC 1996). Protein can be supplemented as either soluble compounds such as those in fresh herbage or less soluble forms including seed meals (Stalker et al. 2006). Ideally, protein is supplied to obtain maximum net protein synthesis in the rumen (Demeyer 1981). Protein supplements are a source of nitrogen and sulphur for the rumen microorganisms and alter the flow rate of digesta, digestibility and increase forage intake (DelCurto et al. 1990b; Siebert and Hunter 1982). Response to protein supplementation varies depending on forage quality and quantity, as well as environmental conditions (Campling 1970; Kartchner 1980). Clanton and Zimmerman (1970) suggest that protein supplementation results in higher BW gain and BCS when forage CP level was low. Low quality forages that have less than 6% CP, generally have greater responses to protein supplementation (Rittenhouse et al. 1970). Microbial fixation of ammonia and sulphide in the rumen bacterial cells is how non-protein nitrogen (NPN) and non-protein sulphur can be utilized as supplements for ruminants (Siebert and Hunter 1982).

2.6.4 Environmental considerations

Grazing cattle is considered to have an environmental advantage because the animal's manure nutrients are being deposited back to the soil from which the forage was taken (Haynes and Williams, 1993). Up to 90 percent of nutrients ingested by grazing cattle may be returned to the land in manure and urine (AAFRD 2009). On pasture, nutrients from manure and urine deposits are generally more concentrated in areas of water, shade and feeding (Franzluebbers et al. 2000). Flores and Tracy (2012) found that hay feeding on pasture in winter could increase

forage production and forage nutritive value by moving hay feeding sites every 2 years to spread out nutrient imports. Excretion of nitrogen, phosphorus, sulfur, and potassium in manure and urine is related to levels in the diet (Ternouth 1989; Morse et al. 1992; Silveira et al. 2010). The majority of nutrients from manure are in the organic form and are not as effective until they are in the inorganic form and are mineralized (Wijnands et al. 1987; Schoenau et al. 2000; Silveira et al. 2010). Eghball et al. (2005) found that manure phosphorus is primarily in its inorganic form and its availability can be as high as 100 percent compared to commercial inorganic phosphorus fertilizer. The organic matter derived from manure application may be beneficial to eroded soils and reduce runoff (Young and Mutchler 1976; Lardner 2003).

Nitrogen is commonly a limiting nutrient in pastures and can be applied as commercial fertilizer, animal manure, or organic forms (Silveira et al. 2010). Forage legumes may also provide adequate nitrogen for forage production through biological fixation of atmospheric nitrogen (Silveira et al. 2010). Excess nitrogen can contaminate water and air with nitrate or ammonia via leaching or nitrous oxide via denitrification (McGechan and Topp 2004). Knowlton and Kohn (1999) suggest that cattle diets exceed animal P requirements by 25 to 40 percent and because of the low bioavailability of dietary P, approximately 80 percent of P consumed is excreted in the manure (Silveira et al. 2010). Accumulated P can leach into groundwater or cause eutrophication of surface waters due to run-off from agricultural land, which increases the amount of land necessary for manure application (Sims et al. 1998; McGechan and Topp 2004; Owens and Shipitalo 2009; Spiehs and Varel 2009).

2.7 Forage quality and chemical composition

It is generally accepted that chemical composition determines forage quality (Van Soest 1965). Two important nutrients that determine forage quality are protein and fiber content (NRC 1996). Forage quality, including protein and fiber content can affect both intake and digestibility and interactions between the two (Van Soest 1965; Siebert and Hunter 1982; McCartney et al. 2006).

2.7.1 Protein determination

Crude protein is estimated based on the quantity of N in the feed from both true protein and NPN, including ammonia, peptides and free amino acids (Sniffen et al. 1992). There are several methods to determine N in feed and include wet chemistry such as the Kjeldahl or LECO procedure and near infrared reflectance spectroscopy (NIRS) (Adesogan et al. 2000). Wet chemistry methods typically calculate N using a conversion factor of 6.25, which Sriperm et al. (2011) has found to overestimate the true protein content of feeds. Techniques to measure true protein are expensive and complex and include ninhydrin assays, colorimetric techniques and liquid chromatography (Adesogan et al. 2000). Protein degradability within the rumen (RDP and RUP), determines the availability of N for rumen microbes, which is important for normal rumen function (Broderick 1994; Van Soest 1994).

2.7.2 Fiber determination

Fiber consists of the cell wall components of plants including cellulose, hemicellulose and lignin and is important for rumen functions such rumination (Moore and Hatfield 1994). Van Soest (1967) developed the detergent system to analyze neutral detergent fiber (NDF) and acid

detergent fiber (ADF) in feeds. Neutral detergent fibre (NDF) contains all three cell wall components and is negatively correlated to forage intake (Mertens 1983). Acid detergent fibre (ADF) contains only cellulose and lignin and is negatively correlated to digestibility (Van Soest 1994).

2.8 Digestibility

Digestibility refers to the fraction of a nutrient that is lost in the digestive tract after ingestion of a feedstuff (Cochran and Galyean 1994; Kitessa et al. 1999). There are several techniques to determine the digestibility of feeds for beef cattle. These techniques include: *in vivo*, *in situ* and *in vitro*. *In vivo* and *in situ* techniques both require cannulated animals and are expensive. *In vitro* techniques are performed in a laboratory and simulate rumen fermentation.

2.8.1 *In vivo*

In vivo digestibility can be measured by calculating the difference between feed intake and fecal output, or by using markers in the feed and calculating the proportion of the marker in the feed versus feces (Van Soest 1994). Total fecal collection is the best technique to determine apparent digestibility, but is not practical for animals in an extensive management system (Cochran and Galyean 1994). Markers can be present as indigestible parts of the feed, or may be added to the feed as long as they are not absorbed or affected by intestinal digestion or microbial fermentation (Van Soest 1994). External markers can be added to the feed, attached to feed particles or dosed into the rumen in several different ways. As a one-time dose, markers are used to estimate passage rate, fluid and particulate size, and dilution rate (Owens and Hanson 1992).

External markers may also be dosed continually or frequently to reach a steady equilibrium, which estimates flow rates at particular points in the digestive system (Owens and Hanson 1992). Dosing with external markers may not be possible in grazing trials, so internal markers are used more often. Examples of internal markers include silica, chromogen, indigestible cellulose, lignin and acid insoluble ash (AIA) (Streeter 1969; Minson 1990; Wilson et al. 1971). Acid insoluble ash has been found to provide the most accurate estimates of digestibility (Wilson et al. 1971) with results similar to those of total fecal collections (Van Keulen and Young 1977).

2.8.2 *In situ*

The *in situ* incubation technique outlined by Orskov and Mehrez (1977) is used to determine the rate and extent of nutrient degradation in the rumen. Feed samples are placed in porous nylon bags and incubated in the rumen for several time intervals. Feed residue remaining after incubation is used to determine the extent and rate of rumen degradation of the feed and its constituents (Orskov and Mehrez 1977). Degradation parameters including soluble, potentially degradable and non-degradable fractions are estimated by fitting disappearance data to either nonlinear or logarithmic-linear mathematical models (Blümmel and Orskov 1993). Results have been found to be variable due to sample size and preparation, bag type, bag surface area, bag porosity, washing and drying procedures, location of bag in the rumen and diet (Orskov et al. 1980; Vanzant et al. 1996; Kitessa et al. 1999). *In situ* incubation experiments are useful in estimating the digestibility of feeds regardless of these sources of variation because microbes have direct access to the feed samples in a natural rumen environment (Aerts et al. 1977; Vanzant et al. 1996).

2.8.3 *In vitro*

Laboratory techniques have been developed to estimate digestibility as an alternative to *in vivo* and *in situ* techniques, which can be expensive and time consuming. Tilley and Terry (1963) developed a two-stage method that provides accurate estimates of rumen digestibility for most feeds with the exception of hay cereal straws (Khazaal et al. 1995). Feed samples are incubated in rumen liquor for 48 h followed by digestion in acidified pepsin for 48 h, which simulates digestion (Kitessa et al. 1999). Since this technique uses rumen fluid to incubate samples, variability in results and reduced reproducibility occur. To overcome variability in results and poor reproducibility, a method involving enzymatic digestion has been developed (Jones and Hayward 1975; Kitessa et al. 1999). The enzymatic digestion method requires feed samples to be incubated in pepsin for 24 h followed by incubation in a cellulase solution for 48 h (Kitessa et al. 1999). Although this method is highly reproducible because of the uniformity of the enzyme, results using this method provide lower digestibility because of a lack in microbial interaction (De Boever et al. 1988).

2.9 Economics

Winter feeding costs are a major contributor to the total cost of production for cow-calf producers (Taylor 2007; Kaliel and Kotowich 2002; Rasby et al. 1990). Kaliel and Kotowich (2002) have reported that 60 to 65% of the total cost of production for cow-calf operations is related to feeding costs for drylot pen systems. Feeding cows in drylot pens over the winter period includes costs for harvesting, handling and transporting feed and removal of manure (Hitz and Russel 1998; Johnson and Wand 1999; Volesky et al. 2002). When dealing with the

economics associated with cow-calf production, it is important to have a least cost production system in place.

Several recent studies indicate that the cost of wintering beef cows can be significantly reduced by grazing them on low quality forages rather than feeding them harvested hay (Anderson et al. 2005; Karn et al. 2005; Willms et al. 1993). Karn et al. (2005) provided evidence for cows that grazed swathed crop over the winter cost US\$0.49 per cow per day, which was US\$0.24 per cow per day less than animals wintered on hay in drylot pens. Research reported by Anderson et al. (2005) suggests that costs per weaned calf and weaning breakeven were both numerically higher for cows fed hay in a drylot compared to those which grazed crop residues over the winter months (Table 2.1).

Table 2.1 Yearly cow cost per cow, cost per calf weaned, and breakeven excluding management, labor and overhead for control (CON) and treatment (TRT) systems				
Item	CON	TRT	P value	SE
No. ^a	99	199	-	-
Initial cow cost, \$	339.75	316.46	-	-
Noncalf revenue, \$ ^b	(53.93)	(48.08)	-	-
Adjusted cow cost, \$ ^c	393.68	364.54	-	-
Cost/weaned calf, \$ ^d	455.12	421.43	0.07	6.83
Breakeven, \$/0.45 kg ^e	0.91	0.84	0.07	0.01

^aNumber of females expected to calve

^bNoncalf revenue = gain/loss cull cows + gain/loss cull heifers

^cAdjusted cow cost = cow cost + noncalf revenue

^dCost per weaned calf = adjusted cow cost/weaning rate (0.865)

^eBreakeven at weaning = (cost/weaned calf/weaning weight (227 kg)

Adapted from: Anderson et al. 2005

Kelln et al. (2011) compared winter feeding systems over three consecutive years and found the cost per cow per day to be numerically lower for the bale grazing and swath grazing systems than the traditional drylot feeding system at \$0.98, \$0.76, and \$1.07 per cow per day,

respectively. The straw-chaff grazing system was found to be the most costly at \$1.27 per cow per day, with \$0.72 of that cost coming from supplement required to meet the nutritional requirements of the cows, while supplement was not fed in the other three systems. Van De Kerckhove (2010) conducted a 2 yr study on the effects of supplementing cows grazing barley straw-chaff with wheat-corn blend DDGS, barley grain, or a 50:50 blend of DDGS and barley grain. In contrast to the findings of Kelln et al. (2011) for the cost of straw-chaff grazing, Van De Kerckhove (2010) found average total costs over 2 yrs to be \$0.77, \$0.77, and \$0.78 per head per day for DDGS, 50:50 blend, and barley grain treatments, respectively. The difference between the total costs for straw-chaff grazing between the two studies is reflective of the amount of supplement fed and the price of the supplement. The amount of supplement required will vary depending on the nutritional quality of the forage and environmental conditions, and the price of the supplement will vary annually depending on current market values (Van De Kerckhove 2010; Kelln et al. 2011). Producers should choose affordable supplements that will meet the nutritional requirements of the animals.

2.10 Summary of Literature Review

In recent years, the beef industry has been looking into alternative management systems that will be economically sustainable for producers. Extending the grazing season for cow-calf producers is one option to reduce winter feeding costs, which have been found to be the greatest cost of production. Options for extending the grazing season include stockpiled forage grazing, swath grazing, bale grazing, and crop residue grazing. Each system has limitations and proper management is required to optimize cow performance, reproductive efficiency and economics.

The hypothesis for the research presented in this thesis is that grazing pea or oat straw-chaff in extensive field systems during winter months with pregnant multiparous beef cows will have similar or improved cow performance and reproductive efficiency as compared to cows managed in a drylot pen system. In addition, system costs will be lower for crop residue grazing compared to wintering cows in drylot pens.

3.0 Effect of utilizing crop residues in winter feeding systems on beef cow performance, reproductive efficiency and economics

3.1 Introduction

In recent years, cow-calf producers have been looking for ways to reduce winter feeding costs. Annual cereal crop residues have been identified as potential sources of feed to reduce winter feeding costs. Little extra cost is required to ensure crop residues are available for grazing since the material can be left in field after a crop has been harvested. Excess cereal crop residues are often burned because in the past they have been thought to have little value (Hutton 2008). The most economical method of utilizing crop residues is to collect the residues in piles after combining the crop where cows can be extensively grazed on the residues. Grazing cows on crop residue piles reduces the costs associated with transporting feed from the field to the drylot location (Hutton 2008). The primary concern of cow-calf producers is to maintain cow performance and reproductive performance through the winter feeding season. To determine the effects of winter feeding, several techniques are used to measure performance and these include determining body weight, rib and rump fat thickness, body condition score (BCS) and reproductive efficiency (McCartney et al. 2004).

Limitations associated with feeding or grazing crop residues include low nutritive value, environmental conditions and using a cost effective supplement. The nutritive value of straw and chaff are too limiting for growing beef cattle and are only suitable for mature beef cows in good body condition (NRC 2000; Hutton 2008). Crop residue nutritive value will vary depending on crop species and variety, maturity at combining and weathering of the residue (McCartney et al. 2006).

Crop residues include both straw and chaff from a cereal or pulse crop and tend to have low protein and high fiber content (NRC 2000). Nutritional characterization of straw and chaff is important when formulating rations using crop residues to ensure adequate supply of nutrients to the animal or avoid feeding nutrients in excess (McCartney et al. 2006). Before allowing cows to graze crop residues, the feed needs to be tested for quality and potential presence of mold levels that may be detrimental to animal health. Residues should be tested for levels of crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF) and energy content should be determined (McCartney et al. 2006). Acid detergent fiber values are often used to estimate the energy content or total digestible nutrients (TDN) of straw based diets (Adams 1995; McCartney et al. 2006). If energy or protein requirements cannot be met by the crop residues alone, supplementation should be considered (NRC 2000; McCartney et al. 2006)). Because of low nutritive value, grazing crop residues requires additional protein and energy supplementation (NRC 2000).

Fiber content is negatively related to the energy content of a feed and also physically limits the volume of feed intake (Van Soest 1994). Straw has limited rumen degradability because it is highly lignified from selecting for lodging resistance for grain production (McCartney et al. 2006). The proportion of plant parts contributes to the overall degradability, such that leaves have the highest degradability, followed by chaff, nodes and internodes (Ramanzin et al. 1986). Environmental factors that have been found to affect DMI include ambient temperature, wind and precipitation, and season or photoperiod. As the ambient temperature falls below the thermoneutral zone, feed intake generally increases (Kennedy et al. 1986; Minton 1986; Young 1986).

Currently there is limited information available regarding beef cows grazing residues from annual crops and whether these residues can provide adequate nutrient and dry matter intake (DMI) required by dry pregnant beef cows. A winter feeding study was conducted during the winter months of 2009-2010 and 2010-2011 at the Termuende Research Ranch, Lanigan, Saskatchewan, to evaluate the effects of grazing crop residues on DMI and performance of dry, pregnant beef cows.

The objectives of this study were:

1. To determine the effects of field grazing oat residue, pea residue or drylot fed mixed grass-legume hay on beef cow performance and reproductive efficiency
2. To determine if oat residue or pea residue can provide adequate nutrients for dry pregnant beef cows with minimal supplementation
3. To characterize the nutritive value of oat residue, pea residue and grass-legume hay
4. To estimate the DMI of crop residues and grass-legume hay
5. To evaluate wintering system costs

3.2 Materials and methods

3.2.1 Study site and crop management

A 2 year winter grazing study was conducted at the Western Beef Development Centre's Termuende Research Ranch near Lanigan, Saskatchewan, Canada (51°51 'N, 105°02 'W). Each year, 16 ha each of pea (cv. Performance 40-10) and oat (cv. Baler) were seeded at a rate of 67.2 and 71.7 kg per ha, respectively. Crops were seeded May 28, 2009 and July 13, 2010. The oat crop received an additional 9.1 kg per ha of actual nitrogen (N) fertilizer at seeding. Weed control was managed using glyphosate [*N*-(phosphonomethyl) glycine], which was applied to

both pea and oat crops each year on June 5, 2009 and July 17, 2010 at 2.6 L/ha (Roundup, Monsanto Inc., Winnipeg, Manitoba, Canada). The oat crop received a mixture of fluroxypyr + 2, 4-D (Attain A, Dow AgroSciences, Calgary, Alberta, Canada), thifensulfuron methyl + tribenuron methyl (Refine SG, E.I. duPont Canada, Mississauga, Ontario, Canada) and nonylphenoxy polyethoxyethanol (Ag-Surf, Viterro Inc., Regina, Saskatchewan, Canada) at 1.3 L/ha applied on July 3, 2009. A mixture of imazamox + imazethapyr (Odyssey, BASF Canada Inc., Mississauga, Ontario, Canada) and naphthalene (Merge, BASF Canada Inc., Mississauga, Ontario, Canada) at 1.2 L/ha was applied to the pea crop on July 3, 2009 and August 6, 2010. Both crops were desiccated with glyphosate (Roundup, Monsanto Inc., Winnipeg, Manitoba, Canada) at 2.5 L/ha on September 28, 2010. In 2009, pea and oat crops were swathed on September 18 and November 3, respectively and combined on September 23 and November 5, respectively. In 2010, both crops were swathed and combined on October 15 and October 16, respectively. Residues (straw chaff) were collected in piles and deposited in the field using a whole-buncher (AJ Manufacturing, Calgary, Alberta, Canada) attached to the combine. Average pile weight was 15.4 kg dry matter (DM) for oat and 16.7 kg DM for pea in 2009 and 17.3 kg DM for oat and 13.7 kg DM for pea in 2010. Each 16 ha field was further subdivided into 3, 5.3 ha paddocks using high-tensile electric fence prior to winter grazing of cows. Nutritive value of oat and pea residue and hay was analyzed by collecting forage samples at start, middle and end of the grazing trial.

The drylot pen system was located 2 km from the field site at the Termuende Research Ranch. Outdoor drylot pens were surrounded by wooden slatted fences with 20% porosity and open faced shelters and water bowls were provided in each pen. Cows were fed mixed grass-

legume hay in round bale feeders and straw was provided as bedding for animal comfort based on the judgement of the herds person.

3.2.2 Grazing animal management

Each year dry, pregnant (yr 1, 108 d pregnant \pm 5 d; yr 2, 82 d pregnant \pm 10 d) Black Angus cows (yr 1, average body weight (BW) = 629 \pm 8 kg; yr 2, average BW = 665 \pm 8 kg) with an average age of 4 years in 2009, were managed in winter feeding systems from November 21, 2009 to January 21, 2010 (62 d) and from November 10, 2010 to November 30, 2010 (20 d). In 2009-2010 90 cows were randomly allocated to 3 different wintering systems, while prior to the trial start in 2010-2011, 12 cows were removed from the study due to injury or failure to conceive, therefore 78 cows were allocated to the second year of the study. Cows were stratified by age, BW and body condition, then randomly allocated to 1 of 3 replicated (n=3) treatments: (1) grazing pea residue piles in field paddocks (PEA); (2) grazing oat residue piles in field paddocks (OAT); or (3) fed round bale grass-legume hay in drylot pens (DL). In 2010-2011, the same cows were re-allocated to the same treatment (diet) they were assigned in 2009-2010.

Cows were allocated crop residue based on BW, pregnancy status, feed nutrient density and environmental conditions in accordance with the NRC (2000) beef model as predicted by CowBytes ration balancing program (Alberta Agriculture, Food and Rural Development 1999). The amount allocated was intended for maintenance of body condition, with no weight gain above that of conceptus growth. In each system, feed was allocated *ad libitum* every 3 d, with a 10% carryover allowed. The amount of crop residue allowed varied depending on winter environmental conditions. Temporary electric fences were used to control animal access to residue piles on a 3 d basis.

Cows assigned to OAT or PEA treatments received additional supplementation of processed oat grain at 0.5% of body weight (Table 3.1). Cows assigned to the DL treatment were supplemented with processed oat grain at 0.06% of body weight in 2009. Dried distiller's grains with solubles (DDGS) was also supplemented to cows on OAT and PEA treatments at 0.06% and 0.02% BW, respectively. OAT treatment cows were provided canola meal as a protein supplement at 0.02% of body weight. Oat grain, DDGS and canola meal were fed in a bunk in each replicate paddock or pen. In 2010, grass-legume hay was supplied to cows on OAT and PEA treatments only during inclement weather or when extreme winter conditions affected residue grazing.

Cows had *ad libitum* access to a 2:1 mineral supplement (20.0% Ca, 10.0% P, 60 ppm Se, 70 ppm Co, 200 ppm I, 3000 ppm Cu, 9000 ppm Mn, 10 000 ppm Zn, 3700 ppm Fe, 1000 ppm F (max), 1 000 000 IU/kg Vitamin A (min), 150 000 IU/kg Vitamin D (min), 1000 IU/kg Vitamin E (min); FeedRite Ltd., Humboldt, Saskatchewan, Canada) fed in tubs, and cobalt-iodized salt (99.0% NaCl (min), 39.0% Na, 150 ppm I, 100 ppm Co; FeedRite Ltd., Humboldt, Saskatchewan, Canada) fed as a block (Table 3.1). Water was supplied daily to each paddock in troughs and two portable wind breaks (10 x 16 m) were supplied for each replicate group of cows.

Table 3.1 Feed ingredient and nutrition composition of rations^z			
Item	Treatment ^y		
	DL	OAT	PEA
Predicted intake (kg DM/hd/d)	15.9	13.1	15.0
Feed (% of ration)			
Forage	97.6	49.5	32.5
Oat grain	1.2	24.8	34.1
DDGS ^x	-	3.5	5.3
Canola meal	-	0.5	-
Supplemented hay	-	19.3	25.5
2:1 Mineral	0.6	1.2	1.3
Salt	0.6	1.2	1.3
Chemical composition ^w			
CP (% DM)	10.5	8.2	10.7
NDF (% DM)	55.2	54.7	49.1
TDN (% DM)	56.4	61.0	59.1
DE (Mcal kg ⁻¹ DM)	2.7	3.0	3.0

^zRations formulated using CowBytes Beef Ration Balancer Program. Version 4. (Alberta Agriculture Food and Rural Development 1999)

^yDL = drylot cows fed grass-legume hay; OAT = oat residue; PEA = pea residue

^xDDGS = dried distiller's grains with solubles

^wCalculated from average nutrient composition of ingredients; CP = crude protein; NDF = neutral detergent fiber; TDN = total digestible nutrients; DE = digestible energy

Cow performance was determined by measuring BW, body condition score (BCS) and subcutaneous body fat thickness at the rump and between the 12th and 13th ribs (Schröder and Staufenbiel 2006). Body weight was recorded over 2 consecutive days at start and end of trial and every 21 d throughout the trial. Cow BW was corrected for conceptus gain using the following equation from NRC (1996):

$$\text{Equation 3.1 } \text{Conceptus weight (kg)} = (\text{calf birth weight} \times 0.01828) \times e^{[(0.02xt)-(0.0000143xtxt)]}$$

Subcutaneous body fat thickness was measured to the nearest 1 mm using an Aloka SSD-500V ultrasound machine and Aloka UST-5044 probe (3.5 MHz). Body condition score was estimated by visual appearance and physical palpation of body fat reserves at the lumbar process

and tail head region (Domecq et al. 1995). Animals were given a score of 1 to 5 (Canadian scale) where 1 is emaciated and 5 is obese (Lowman et al. 1976).

3.2.3 Estimation of forage utilization

Dry matter intake was estimated using the herbage disappearance method for forages as described by Volesky et al. (2002) and Kelln et al. (2011). Prior to grazing, 40 crop residue piles in each replicate paddock and 3 bale sites in each replicate pen were weighed to determine average pile and bale weight (kg). Moisture samples of forages were taken to determine the weight of residue and hay available on a dry matter (DM) basis. To determine post-grazed residual weight of remaining crop residue and hay, all material was weighed using the same procedure. Daily forage DMI intake was estimated by calculating the difference between pre- and post-grazing weight of crop residue piles and hay bales using the following equation:

$$\text{Equation 3.2 } DMI (kg) = \frac{(kg DM p^{-1} allocated - kg DM p^{-1} residual)}{n^{-1}/p}$$

where p = the number of days per graze period and n = the number of cows per experimental unit (Volesky et al. 2002).

3.2.4 Environmental data

Daily minimum and maximum temperatures and precipitation, were obtained from Environment Canada Climate Data Online (www.climate.weatheroffice.ec.gc.ca) for Watrous and Esk, Saskatchewan, approximately 5 km SE of the study site (51°48 'N, 104°51 'W) (Table A.1).

3.2.5 Estimation of crop residue biomass

Each year, before harvesting field crops, 20, 0.25-m² quadrats were sampled in each replicate field paddock, then dried to calculate DM yield for each crop. Oat whole crop biomass was 12,799 and 6,519 kg ha⁻¹ in 2009 and 2010, respectively. Pea whole crop biomass was 9,531 and 3,739 kg ha⁻¹ in 2009 and 2010, respectively. The major factor affecting crop biomass in 2010 was the 200% increase in precipitation (Table A.1), which affected seeding conditions, crop establishment and maturity. Post-harvest, crop residue yield for both crops was determined by weighing 50 residue (straw + chaff) piles in each of 3 replicate paddocks (n=150) and calculating weight on a DM basis. The average pile weight was multiplied by the number of piles per paddock to determine the DM yield of available crop residue per hectare. The crop residue (straw + chaff) yield for oat was 2,194 and 714 kg ha⁻¹ in 2009 and 2010, respectively. The crop residue yield for pea was 1,218 and 624 kg ha⁻¹ in 2009 and 2010, respectively. Differences in whole crop and crop residue biomass between years can be attributed to the 200% increase in rainfall in 2010 (Table A.1).

3.2.6 Laboratory analysis

Crop residue samples from each replicate field paddock and hay samples from each replicate drylot pen were collected at the start, middle and end of each trial period. Supplemental feed samples were also collected. Prior to lab analysis all samples were dried at 55°C for 48 h and ground to pass through a 1-mm screen with a Retsch ZM-1 grinder (Haan, Germany). All feed samples were analyzed for moisture, ash, crude protein (CP), ether extract (EE), acid detergent fiber (ADF), neutral detergent fiber (NDF), acid detergent lignin (ADL) and acid detergent insoluble nitrogen (ADIN). Total digestible nutrients (TDN) (% DM) were calculated

for forage samples using the Weiss et al. (1992) equation. Calcium (Ca) and phosphorus (P) were analyzed by Central Testing Laboratory Ltd. (Winnipeg, Manitoba, Canada).

Moisture and ash were determined according to the procedures outlined by the Association of Official Analytical Chemists (method #930.15; AOAC 2000). Crude protein (N x 6.25) and ADIN concentrations were determined using the Kjeldahl procedure (method #984.13; AOAC 2000) using the 2400 53 Kjeltec Analyzer Unit (FOSS Tecator, Hoganas, Sweden). Neutral detergent fiber and ADF (method #973.18; AOAC 2000) were analyzed according to the Labconco procedure. Acid detergent lignin content was evaluated using the beaker method outlined by ANKOM Technology (method # 973.18; AOAC 2000). Ether extract was determined according to the procedure outlined by the AOAC (method #920.39; AOAC 2000).

3.2.7 Statistical analysis

The Proc Mixed Model of SAS (2009) was used to analyze all data except cow body condition score. Differences were considered significant when $P \leq 0.05$, and means were separated using Tukey's multiple range test (Steel et al. 1997). Dry matter intake, BW, rib and rump fat, and reproductive data (calving rate, calf birth weight, calf birth date, first and last calf born, calving span and calving pattern) were analyzed as fixed effects in a randomized complete block design (RCBD) with year considered as the random effect. The experimental model was:

$$Y_{ij} = \mu + \rho_i + \alpha_j + e_{ij}$$

where μ is the overall mean, ρ_i is the block or random effect to the i th year, α_j is the fixed effect of the j th treatment, and e_{ij} is the error term specific to the experimental unit (group of cows) assigned to the j th treatment within the i th year.

In addition, a one way ANOVA of the Proc Mixed Model procedure of SAS (2009) with a two way (year by treatment) interaction was conducted on cow BW from the first 20 d of the 2009-2010 trial period and the total 2010-2011 trial period (20 d) due to the difference in trial length in each year. Data for both years was also analyzed individually because of the difference in trial length from 62 d in 2009-2010 to 20 d in 2010-2011. Cow BCS data were analyzed using the Proc Glimmix procedure of SAS (2009), because BCS values have no unit and are subjective estimates. Proc Glimmix is used to fit statistical models to data with correlations or non-constant variability and where the response is not necessarily normally distributed (SAS Institute Inc. 2009).

3.3 Results and discussion

3.3.1 Forage and supplement quality

Nutritive value of hay, crop residue and supplements are presented in Table 3.2. Total digestible nutrient values calculated using the Weiss equation (Weiss et al. 1992) were 61.4, 59.1 and 50.2% of DM for mixed hay, oat residue and pea residue, respectively in 2009. In 2010, TDN values were 52.3, 66.9% and 56.9% of DM for mixed hay, oat residue and pea residue respectively. Hutton (2008) reported that energy levels (TDN) for oat residue and pea residue ranged from 38.9 to 51.3% and 35.0 to 45.2%, respectively. These values are lower than TDN levels of residues found in both years in the current study. Higher TDN levels were observed for both the oat and pea residue in 2010, possibly due to delayed growing conditions, which prevented both crops from reaching full maturity (McCartney et al. 2008). Average temperature was similar during the growing season from June to September for both years of the study at 15, 16, 16 and 13°C, respectively (Table A.1) however, total precipitation received during April to

November was 200% greater in 2010 compared to 2009, 637 vs 334 mm, respectively (Table A.1). The increased moisture in spring caused delayed seeding of both crops until July 13 in 2010. In contrast, both crops were seeded on May 28 in 2009, 45 d earlier than in 2010. The delayed seeding date in 2010 prevented the field crops from reaching maturity prior to combining (McCartney et al. 2008; MAFRI 1985).

Table 3.2 Chemical composition of forages and supplements (dry matter basis)

Item ^z	Mixed Hay	Oat Residue	Pea Residue	Oat Grain
2009 ^y				
CP (% DM)	8.8 ± 0.29	2.9 ± 0.47	7.3 ± 1.08	12.8 ± 0.14
NDF (% DM)	53.0 ± 2.10	78.5 ± 4.16	74.1 ± 1.43	26.2 ± 1.05
ADF (% DM)	33.3 ± 5.32	46.8 ± 3.36	58.2 ± 5.38	6.5 ± 0.32
EE (% DM)	1.4 ± 0.03	0.8 ± 0.20	0.9 ± 0.05	0.3 ± 0.17
Calcium (% DM)	0.8 ± 0.09	0.2 ± 0.02	1.0 ± 0.03	0.1 ± 0.01
Phosphorus (% DM)	0.1 ± 0.01	0.2 ± 0.02	0.2 ± 0.02	0.4 ± 0.02
ADIN (% DM)	1.2 ± 0.01	0.6 ± 0.01	2.7 ± 0.01	0.2 ± 0.01
TDN (% DM)	61.4 ± 2.37	59.1 ± 0.40	50.2 ± 0.72	75.7 ± 0.71
2010				
CP (% DM)	12.3 ± 0.74	5.3 ± 0.18	8.9 ± 0.68	12.2 ± 0.27
NDF (% DM)	59.3 ± 2.32	55.0 ± 1.17	49.0 ± 0.27	32.4 ± 4.55
ADF (% DM)	36.8 ± 1.78	29.7 ± 2.51	38.2 ± 0.17	14.0 ± 3.92
ADL (% DM)	8.7 ± 0.67	3.0 ± 0.05	9.1 ± 0.50	2.7 ± 0.44
EE (% DM)	1.3 ± 0.06	2.4 ± 0.40	1.8 ± 0.23	0.7 ± 0.05
Calcium (% DM)	0.8 ± 0.02	0.5 ± 0.15	1.2 ± 0.03	0.1 ± 0.01
Phosphorus (% DM)	0.3 ± 0.05	0.3 ± 0.03	0.3 ± 0.02	0.4 ± 0.01
ADIN (% DM)	0.9 ± 0.01	1.1 ± 0.01	2.6 ± 0.01	1.3 ± 0.03
TDN (% DM)	52.3 ± 1.27	66.9 ± 3.07	56.9 ± 1.03	76.2 ± 2.53

^zCP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; ADL = acid detergent lignin; EE = ether extract; ADIN = acid detergent insoluble nitrogen; TDN = total digestible nutrients

^y2009 lignin values are not reported due to laboratory problems in 2009 resulting in unreliable lignin values. 2009 TDN values for oat and pea residues were calculated using 2010 lignin values

Additionally, residue fiber levels (NDF and ADF) are lower for oat and pea residue in 2010 compared to 2009 fiber levels (Table 3.2). Neutral detergent fiber values were 30 and 34%

higher for oat residue and pea residue in 2009 compared to 2010, respectively and 11% lower for mixed hay in 2009 compared to 2010. Acid detergent fiber values were 37 and 34% higher for oat residue and pea residue in 2009 compared to 2010, respectively and 10% lower for mixed hay in 2009 compared to 2010. Residue lignin values in 2009 were considered unreliable due to laboratory problems in 2009 with the lignin analysis method. Lignin values from 2010 were used to calculate TDN for oat and pea residue in 2009 using the Weiss equation (Weiss et al. 1992). Fiber values were higher for 2009 residues compared to 2010 residues because in 2009, both crops reached maturity, while in 2010 crops were immature at combining. In 2010, the oat crop only reached the late boot stage and the pea crop reached the flowering stage of maturity. Oat crops require approximately 60 d to reach the heading stage (Todd and Spaner 2003) and 100 d to reach maturity (MAFRI 1985; Todd and Spaner 2003) while pea crops require approximately 90 d to reach maturity (MAFRI 1985). Since both crops were seeded on July 13 in 2010 there were not enough days to reach maturity before the frost in mid September (Environment Canada's Climate Data Online). As the growing season progresses and plants mature, structural stem materials increase, including lignin, cellulose and hemicellulose, which reduce forage quality and digestibility (Wilson 1982; Jones and Wilson 1987; Huston and Pinchak 1991; Van Soest 1994; Holechek et al. 2004).

In both years, CP level of the oat residue was very low at 2.9 and 5.3% DM for 2009 and 2010, respectively. The recommended CP requirement for a pregnant beef cow during second trimester of pregnancy is 7.8 percent (NRC 2000). Hutton (2008) reported that CP level of oat residue can range from 2.8 to 7.4% with an average CP level of 5.1 percent. The CP level of pea residue was 7.3 and 8.9% in 2009 and 2010, respectively, which is similar to pea CP levels reported by Hutton (2008), ranging from 4.6 to 9.4 percent. In 2009, ADIN values were 25 and

4% higher for mixed hay and pea residue respectively, and 45% lower for oat residue in 2009 compared to 2010. Calcium and P requirements for beef cows are 0.24 and 0.17% DM (NRC 2000), which was met by all forages in both years of the study (Table 3.2). Straw-based diets usually require supplemental CP, energy, Ca and P to meet beef cattle nutrient requirements (McCartney et al. 2006).

Sources of variation in nutrient content of cereal chaff includes different species of cereal crops (McCartney et al. 2006) and different cultivars within species (Coxworth et al. 1981; Kernan et al. 1984; Kernan et al. 1991; Erickson et al. 1982; White and Bergman 1985). Straw quality may be improved through selection without compromising yield and quality of grain (Erickson et al. 1982; Capper et al. 1989; Ramanzin et al. 1991). Capper (1988) found that dwarf and semi-dwarf cultivars contain lower proportions of stem and higher proportions of leaf blade than taller cultivars. Leaf blades are more digestible than stem from cereal crops, which causes dwarf cultivars to have improved nutrient content (Capper 1988). Under the extremely poor growing conditions in 2010 of the current study, crops were immature at combining and may have had improved nutrient content similar to that of dwarf cultivars.

The type of combine influences residue yield and quality such that a rotary combine causes increased mechanical damage to straw compared to a conventional combine (PAMI 1998). This increase in damage to straw causes straw and chaff to be less collectable and more difficult to transport. Weathering of straw after combining and before baling increases NDF, ADF and lignin content (Kjos et al. 1987). Kjos et al. (1987) allowed wheat, oat and barley straw to weather for 1 month and found that NDF, ADF and lignin increased by 80, 140 and 49 g kg⁻¹, respectively. High moisture content of straw and chaff can cause fungal and microbial growth resulting in DM loss (McCartney et al. 2006). Feeding moldy straw or chaff to cows includes

risks such as mycotic abortion, haemorrhagic disease, aspergillosis, fungal toxicosis (Lacey 1979) and liver damage (McCartney et al. 2006). Prior to feeding straw and chaff, it should be tested for mycotoxins to ensure levels are safe (NRC 2000). In 2009, pea residue was analyzed for the presence of mold and was reported to be 2600 cfu g⁻¹, and the types of mold found included fusarium, botrytis, geotrichum, mucor, rhizopus and penicillium. Mucor, rhizopus and penicillium have been found to cause reproductive problems in cattle (Knudtson and Kirkbride 1992). There are no solid recommendations for safe mold counts as recommendations for high mold counts range from 100,000 to 1,000,000 cfu g⁻¹ (MAFRI 1985).

3.3.2 Estimation of dry matter intake

Estimated total DMI for the DL treatment cows was significantly greater ($P < 0.01$) compared to the OAT and PEA treatment cows, in both years of the study (Table 3.3). In 2009, total DMI was 15.9, 9.2, and 8.5 kg per day, or 2.6, 1.6, and 1.4% of BW per day for DL, OAT and PEA treatments, respectively. In 2010, total DMI was 15.6, 7.5, and 6.5 kg per day, or 2.3, 1.2, and 1.0% of BW per day for DL, OAT and PEA treatments, respectively. Supplementation levels of oat grain between DL, OAT, and PEA systems were also different ($P < 0.01$) in 2009, with OAT and PEA cows receiving greater levels than DL cows (Table 3.3). Supplement levels were determined using CowBytes software (AAFRD 1999) to meet energy and protein requirements of OAT and PEA residue grazing cows in field paddock. The low estimated DMI of cows on the OAT and PEA treatments may also be explained by the high NDF value of the crop residues (Table 3.2), poor palatability of residue and severe environmental conditions (Mertens 1983; Young 1986; Adams 1987; Capper et al. 1989). OAT and PEA cows only consumed 1.0 and 0.7% BW of residue. Mertens (1983) reported the predicted DMI of forages to

be 1.2% of BW as neutral detergent fiber. This is similar to intake predictions using the NRC (2000) beef model in the CowBytes Ration Balancing Program (AAFRD 1999), which estimates that pregnant beef cows in the second trimester can only consume 1.2% of BW as straw.

Table 3.3 Estimated dry matter intake of hay, oat residue or pea residue

Item	Treatment ^z			SEM	P value
	DL	OAT	PEA		
2009-2010					
Dry matter intake, kg d ⁻¹					
Forage	15.5a	6.1b	4.6c	0.07	< 0.01
Oat grain	0.4c	2.8b	3.5a	0.01	< 0.01
DDGS ^y	-	0.2	0.4	-	-
Canola meal	-	0.1	-	-	-
Total	15.9a	9.2b	8.5b	0.08	< 0.01
Dry matter intake, % BW					
Forage	2.5a	1.0b	0.7c	0.01	< 0.01
Oat grain	0.1c	0.4b	0.6a	0.01	< 0.01
DDGS	-	0.1	0.1	-	-
Canola meal	-	0.1	-	-	-
Total	2.6a	1.6b	1.4b	0.01	< 0.01
2010-2011					
Dry matter intake, kg d ⁻¹					
Forage	15.6a	2.7b	0.8b	0.84	< 0.01
Supplemented hay	-	3.1	3.5	-	-
Oat grain	-	1.4	1.8	-	-
DDGS	-	0.3	0.4	-	-
Total	15.6a	7.5b	6.5b	0.95	< 0.01
Dry matter intake, % BW					
Forage	2.3a	0.4b	0.1b	0.02	< 0.01
Supplemented hay	-	0.5	0.5	-	-
Oat grain	-	0.2	0.3	-	-
DDGS	-	0.1	0.1	-	-
Total	2.3a	1.2b	1.0b	0.03	< 0.01

^zDL = drylot cows fed grass-legume round bale hay; OAT = cows grazing oat residue in field paddocks; PEA = cows grazing pea residue in field paddocks

^yDDGS = dried distiller's grains with solubles

a-c Means with different letters in the same row are significantly different (P<0.05)

SEM = standard error of the mean

In addition, poor palatability of forage has been found to decrease intake (Arnold 1960). Poor palatability may be a reason for the low DMI of pea residue possibly due to presence of chemical compounds, mold and high fiber content (Kjos et al. 1987). Plant factors have also been found to affect forage palatability and include plant species, chemical composition, physical composition, maturation and forage type (Marten 1978; Blackburn 1991). Preference is generally given to selection of leaf over stem and green, immature material over dry, mature material (Cook and Harris 1950; Cook et al. 1956; Arnold 1963). Ohlde et al. (1992) suggested that nodes may have an impact on straw intake and observed that most of the forage refused in straw feeding trials consisted of stem portions a few centimeters from a node. When compared to the material provided, the material consumed is usually higher in phosphate, CP and energy (Cook et al. 1956; Arnold 1960). Gherard and Black (1991) found that when a forage is offered alone palatability has little effect on voluntary intake, however rate of consumption may decrease.

According to NRC (2000), maintenance requirements for a 533 kg beef cow are calculated to be between 8.87 and 9.72 Mcal of NE_m per day. Pregnancy requirements for a cow at 120 d of gestation are between 0.32 and 1.18 Mcal of NE per day (NRC 2000). In the current study, DMI of oat and pea residue in 2009 was calculated to be 6.1 and 4.6 kg per day, or 1.0 and 0.7% of BW, respectively. Dry matter intake of oat and pea residue in 2010 was calculated to be 2.7 and 0.8 kg per day, or 0.4 and 0.1% of BW, respectively. To meet energy requirements of cows grazing oat and pea residue during extreme winter weather conditions, it was necessary to provide additional energy supplements such as oat grain, DDGS and grass-legume hay. In 2009, digestible energy (DE) content of oat and pea residue was 2.1 and 1.7 Mcal kg⁻¹ DM, respectively. In 2010, DE content of oat and pea residue was 2.9 and 2.6 Mcal kg⁻¹ DM, respectively. Based on the calculated residue DE values, cows would need to consume 10.1 to

11.0 kg of oat residue or 16.1 to 17.7 kg of pea residue in 2009, and 6.0 to 6.5 kg of oat residue or 6.9 to 7.6 kg of pea residue in 2010 to meet calculated maintenance requirements of 8.87 to 9.72 Mcal of NE_m per day (NRC 2000). Since maximum DMI of crop residue NDF is approximately 1.2% BW (NRC 2000), or 7.6 kg for a 630 kg beef cow, the cows grazing OAT or PEA residue in 2009, would not be able to consume enough DM to meet NE_m requirements, therefore an additional 2.18 to 3.03 and 4.69 to 5.54 Mcal of energy needed to be supplied daily to the OAT and PEA residue grazing cows, respectively. In 2010, cows should have been able to consume enough residue to meet NE_m requirements, however it could be suggested that palatability limited intake (Holt 1993).

A decrease in time spent grazing and DMI of residue was observed for oat and pea residue grazing cows during severe winter weather conditions which included snow and ice build-up and extremely cold temperatures with notable wind speeds (Table A.1; December 2009, November 2010). The average temperature during the study in 2009 was -14 °C with 11.8 cm of snow, while in 2010 the average temperature during the trial was -11 °C with 25.2 cm of snow. Adams et al. (1986) studied winter grazing activity of cows and found that time spent grazing decreased as mean daily temperature decreased to -27 °Celsius. In 2010, supplemental hay was provided for the last 8 d to meet the animal nutrient requirements when residue DMI decreased. However, once hay supplementation was provided, cows were observed to consume less residue, possibly due to the animal's preference for hay rather than residue (Van De Kerckhove 2010). The current study period was 62 d in length in 2009 compared to 20 d in 2010. However, snow depth in 2010 was two-fold compared to 2009, which may also have affected animal accessibility to the residue piles (Kelln 2010). Kelln (2010) observed that freezing rain, snowfall and drifting snow made feed inaccessible in field grazing systems. In the first year of a winter

grazing study at Lanigan, Kelln (2010) reported no snowfall prior to the trial start and only 470 mm throughout the study period, while in the second year, a total of 825 mm of snowfall was received from the start to the end of the study period. Animal access to residue piles and swaths was limited due to snow depth (Kelln 2011). Several factors have been reported to affect time spent grazing including acute cold stress (Adams et al. 1986; Adams 1987), photoperiod (NRC 2000), acclimation and nutritional quality of the diet (Young 1986) and forage availability (Rayburn 1986). Baron et al. (2006) reported a 33% decrease in DMI and attributed this to inaccessibility of swaths for field grazing due to severe winter weather conditions. Differences in feed quality between years were also reported and related to variations in precipitation and temperature during the growing season of the crops (Baron et al. 2006).

3.3.3 Cow performance and reproductive efficiency

Initial cow BW was greater ($P < 0.01$) for the DL and OAT cows compared to the PEA cows when data from the first 20 d were pooled over 2 years (Table 3.4). Final cow BW was different ($P < 0.01$) between all 3 winter feeding systems, with DL cows having greater final BW (681 kg) and PEA cows grazing pea residue having the lowest final BW (626 kg) (Table 3.4). The change in BW was also greater ($P < 0.01$) for cows on the DL treatment compared to cows on the OAT and PEA treatments. The PEA residue grazing treatment was the only system where cows had a negative BW change, which was -16 kg over the 20 d period. Analysis of the first 20 d of the 2009-2010 study and the total 2010-2011 study periods, showed a significant ($P < 0.01$) year by treatment interaction for final BW and BW change. This interaction can be explained by the difference in BW change from the 2009-2010 study period when cows had a positive BW change compared to the negative BW change observed in the 2010-2011 study

period (Table 3.4). The differences ($P < 0.01$) in initial BW, final BW and BW change between the first 20 d of the 2009-2010 study period and the total 2010-2011 study period (20 d) suggest feed quality and weather conditions may cause difficulties in winter grazing systems.

Table 3.4 Effect of winter feeding system on beef cow body weight over 20 d period for 2 yr

Item	Body weight ^z , kg		
	Initial	Final	Change
Year			
2009-2010	629b	641b	12a
2010-2011	665a	663a	-2b
SEM	1.3	2.8	2.1
Treatment ^y			
DL	649a	681a	32a
OAT	651a	657b	6b
PEA	642b	626c	-16c
SEM	1.6	3.4	2.5
P-value			
Year	< 0.01	< 0.01	< 0.01
Trt	< 0.01	< 0.01	< 0.01
Year*Trt	0.25	0.01	< 0.01

^zCow BW adjusted for conceptus gain

^yDL = drylot cows fed grass-legume round bale hay; OAT = cows grazing oat residue in field paddocks; PEA = cows grazing pea residue in field paddocks

a-c Means with different letters in the same column are significantly different ($P < 0.05$)

SEM = standard error of the mean

Kelln et al. (2011) studied the effect of winter feeding systems on cow BW and BCS change over a 3 year period. Cows grazing barley residue piles in field paddocks were compared to cows fed mixed grass-legume round bale hay in drylot pens. In year one of the study during the first 21 d, the residue grazing cows had a negative BW change of -6.5 kg, while the drylot treatment had a positive BW change of 9.1 kilograms. In years 2 and yr 3, BW change was lower ($P < 0.01$) for the barley residue grazing cows compared to the drylot managed cows (year 2, 6.5 and 32.9 kg; year 3, 1.6 and 16.5 kg for residue and drylot, respectively). Although BW change was found to be less for residue grazing cows than for cows fed grass-legume hay in drylot pens,

the cows grazing barley residue in field paddocks were still found to have an average positive BW change over the 3 year study (Kelln et al. 2011).

Analysis of the entire trial periods (62 d, 2009-2010; 20 d, 2010-2011) indicate no difference in initial BW in 2009 (Table 3.5). However, in 2009-2010, final BW and BW change were different ($P < 0.01$) between cows on all 3 treatments (Table 3.5). Final BW after 62 d was 695, 665 and 635 kg and BW change was 66, 32 and 10 kg for DL, OAT and PEA cows, respectively. The change in rib and rump fat was also different ($P < 0.01$) with DL cows rib fat increasing 1.5 mm and PEA cows losing -1.7 mm of rib fat. Drylot cow rump fat increased 4.0 mm and PEA cow rump fat decreased -1.4 millimeters.

Kelln et al. (2011) found differences in final BW and BCS change ($P < 0.05$) for the entire trial period in yr 1 (78 d) and yr 3 (36 d). Swath grazing cows lost BW (-8.0 kg) during yr 1, while straw-chaff grazing, bale grazing and drylot pen fed cows gained body weight. During yr 1, cow BW after 21 d compared to after 78 d increased by 17.9, 15.7, 15.9, and 14.3 kg for bale grazing, swath grazing, straw-chaff grazing, and drylot pen fed cows, respectively. This increase in BW during the last 57 d may be a result of compensatory gain, feed access limitation or cows having less experience in extensive field grazing (Kelln et al. 2011).

McCartney et al. (2004) studied cows swath grazing in field paddocks and found that they had lower BW gain and back fat compared to cows fed in drylot pens. Although pre-breeding BW was lower for cows in the swath grazing system, subsequent breeding was not affected (McCartney et al. 2004). Karn et al. (2005) studied the effects of cows swath-grazed on oat, pea, and triticale crop residue and swathed corn, or swathed western wheatgrass during the winter months in Nebraska. Supplementation was required to maintain BW and BCS similar to cows fed hay in drylot pens (Karn et al. 2005).

Legesse et al. (2012) evaluated cow performance for four winter feeding strategies in the western Canadian Parkland, including extended-grazing of dormant regrowth of perennial pastures and swathed annual crops, or one of three diets fed in a drylot: hay, oat straw with steam-rolled barley grain, and barley silage with oat straw. Cows in the extended-grazing treatment maintained BW better than those in the drylot treatments, especially those cows receiving the barley silage with oat straw diet. Lower BW was found in yr 5 ($P < 0.05$) for extended grazing cows due to drought (Legesse et al. 2012). During production years with adequate precipitation in the growing period, the extended-grazing strategy may be an alternative to feeding cows in drylot pens. With adequate supplementation, oat straw can be a useful alternative for drylot pen feeding (Legesse et al. 2012).

In 2010-2011, initial BW, final BW and BW change were different ($P < 0.01$) between DL and PEA cows, and between ($P < 0.01$) OAT and PEA cows (Table 3.5). Initial BW was 2% lower ($P < 0.01$) for PEA cows compared to DL and OAT cows, and final BW was 6 and 4% lower ($P < 0.01$) for PEA cows compared to DL and OAT cows, respectively. Change in BW was 180 and 150% lower ($P < 0.01$) for PEA cows compared to DL and OAT cows, respectively.

Differences observed in cow BW and rib and rump fat measurements may be the result of differences observed in residue DMI between the residue grazing and drylot pen wintering systems. Pooled data from the first 20 d of both study years, showed DL cows had the greatest positive change in BW, rib fat and rump fat and the greatest DMI of forage, while PEA cows had negative change in BW, rib fat and rump fat and the lowest dry matter intake. These results may suggest an adaptation period may have occurred and that the cows needed an adjustment period to consuming the pea residue. In 2009, the residue grazing cows showed increased BW over the

Table 3.5. Effect of winter feeding system on beef cow performance

Item	Treatment ^z			SEM	P value
	DL	OAT	PEA		
2009-2010 (62 d)					
Body weight ^y , kg					
Initial	629	633	625	2.9	0.23
Final	695a	665b	635c	5.2	<0.01
Change	66a	32b	10c	3.0	<0.01
Rib fat, mm					
Initial	3.7	4.1	5.2	0.32	0.11
Final	5.1	4.1	3.5	0.58	0.21
Change	1.5a	0.0b	-1.7c	0.08	<0.01
Rump fat, mm					
Initial	3.5	4.1	5.6	0.56	0.09
Final	7.4	4.6	4.2	1.11	0.06
Change	4.0a	0.5b	-1.4c	0.24	<0.01
2010-2011 (20 d)					
Body weight, kg					
Initial	669a	669a	658b	3.10	<0.01
Final	684a	675a	646b	25.03	<0.01
Change	15a	6a	-12b	13.23	<0.01
Rib fat, mm					
Initial	4.3	5.2	4.6	0.47	0.49
Final	3.6	4.7	3.7	0.88	0.49
Change	-0.7	-0.6	-1.0	0.44	0.83
Rump fat, mm					
Initial	4.3	4.2	4.5	0.34	0.91
Final	3.9	4.7	3.7	0.33	0.26
Change	-0.4	0.5	-0.8	0.33	0.17

^zDL = drylot cows fed grass-legume round bale hay; OAT = cows grazing oat residue in field paddocks; PEA = cows grazing pea residue in field paddocks

^yCow BW adjusted for conceptus gain

a-c Means with different letters in the same row are significantly different (P < 0.05)

SEM = standard error of the mean

final 42 d of the trial, 26 and 29 kg (data not shown) for OAT and PEA cows, respectively. Kelln et al. (2011) also observed an increase in BW of 14 kg for swath grazing cows over the last 57 d of the study, with cows losing 23.7 kg over 21 d, yet only 8 kg over the entire 78 d study. Fernandez-Rivera and Klofenstein (1989) suggest that an adaptation period is required for naive cows when grazing corn stalk residue. In the current study, the adaptation period required for cows grazing PEA or OAT residue may have allowed for compensatory gain once the cows were adapted to consuming the residue and DMI increased. Fox et al. (1972) explained that compensatory gain is the increase in BW which results from nutritionally restricted animals being placed on a higher plane of nutrition. This may help explain the increase in BW in 2009 over the last 42 d of the current study.

Van De Kerckhove et al. (2011) conducted a 2 year study to determine the effects of supplementing wheat-corn blend dry distiller's grains with solubles (DDGS) on performance of beef cows grazing barley crop residue. Cows supplemented with 100% DDGS or 50:50 DDGS:barley grain had greater ($P < 0.01$) positive BW change than cows supplemented with 100% rolled barley grain. Cows supplemented with 100% DDGS, 50:50 DDGS:barley grain, or 100% rolled barley grain had BW change of 11.3, 6.8, and -6.5 kg per animal, respectively. These results suggest that supplemented wheat-corn blend DDGS can enhance the utilization of barley crop residue. A difference in the calculated compared to actual energy density of supplements may also exist. According to Adams (1995), barley grain has a higher DE content (4.0 Mcal kg^{-1}) than DDGS (3.4 Mcal kg^{-1}), therefore cows supplemented with barley grain would be expected to have greater performance. In contrast, Van De Kerckhove et al. (2011) reported the opposite, which suggests that DDGS may have had a greater energy value than calculated from laboratory analysis.

In the current study, cows grazing oat and pea residues were supplemented with a blend of oat grain and dried distiller's grains with solubles. In both 2009 and 2010, the pea residue grazing cows were provided a greater amount of supplement, yet consumed less pea residue than the oat residue grazing cows. The increased amount of oat grain and DDGS provided to the pea residue cows was to offset the low energy content of pea residue. The decreased DMI of pea residue was not anticipated as a result of increasing the oat grain and DDGS amount and is predicted to be because of poor palatability of the pea residue.

The effect of winter feeding system on body condition score (BCS) is presented in Table 3.6. No differences ($P > 0.05$) were observed for BCS between the DL, OAT and PEA cows. This may be explained by Lowman et al. (1976) who suggested that to detect a BCS change of 0.5, a BW change of 50 kg is required. In the current study, only the pea residue grazing cows lost BW of 16 kg (Table 3.4) when data was pooled over 2 years and these same cows lost only 12 kg in 2010 when BW data were analyzed by year (Table 3.5). Similar to BCS results in the current study, Van De Kerckhove (2010) found no differences in BCS between type of supplementation strategy for cows grazing barley residue piles.

However, in contrast to the current study other research has reported that when grazing different crop residues cow BCS was affected (Anderson et al. 2005; Wood et al. 2010; Karn et al. 2005). Anderson et al. (2005) conducted a 3 yr study to evaluate animal performance between cows grazing pasture and corn residue, compared to cows grazing pasture only. After the grazing period, BCS was greater ($P < 0.01$) for cows grazing pasture only compared to those grazing corn residue. The difference in cow BCS between treatments was suggested to be due to variation in forage quality and availability (Anderson et al. 2005).

Table 3.6 Effect of winter feeding system on beef cow body condition score

BCS	Treatment ^z			SEM	P value
	DL	OAT	PEA		
2009					
Start of trial (% of cows)					
2	0.0	3.3	6.7	1.87	0.85
2.5	73.3	69.6	58.9	4.94	0.58
3	16.7	20.4	17.4	4.11	0.76
3.5	10.0	6.7	3.3	2.61	0.63
4	0.0	0.0	10.4	2.07	1.00
End of trial (% of cows)					
2	0.0	7.0	20.7	2.96	0.40
2.5	56.7	76.3	61.9	5.01	0.36
3	23.3	13.3	13.7	3.97	0.57
3.5	16.7	3.3	0.0	2.53	0.37
4	3.3	0.0	3.7	1.57	1.00
Change (% of cows)					
-1	0.0	0.0	13.3	2.60	0.36
-0.5	6.7	27.4	27.8	3.40	0.63
0	66.7	62.6	58.9	4.69	0.21
0.5	20.0	10.0	0.0	2.57	1.00
1	3.3	0.0	0.0	1.09	1.00
1.5	3.3	0.0	0.0	0.00	1.00
2010					
Start of Trial (% of cows)					
2	12.0	7.4	11.6	3.45	0.84
2.5	37.5	48.1	44.4	5.60	0.78
3	34.7	18.5	20.4	4.79	0.39
3.5	7.9	14.8	15.7	3.77	0.66
4	7.9	11.1	7.9	3.22	0.89
End of Trial (% of cows)					
2	19.0	14.8	24.1	4.47	0.72
2.5	57.4	44.4	56.0	5.62	0.60
3	7.9	29.6	12.0	4.04	0.18
3.5	15.7	7.4	3.7	3.18	0.43
4	0.0	3.7	4.2	1.78	1.00
Change (% of cows)					
-1	11.6	7.4	11.6	3.45	0.84
-0.5	34.3	25.9	36.6	5.27	0.71
0	38.4	63.0	51.9	5.55	0.28
0.5	15.7	0.0	0.0	2.36	1.00
1	0.0	0.0	0.0	0.00	1.00
1.5	0.0	3.7	0.0	1.21	1.00

^zDL = drylot cows fed grass-legume round bale hay; OAT = cows grazing oat residue in field paddocks; PEA = cows grazing pea residue in field paddocks
SEM = standard error of the mean

Wood et al. (2010) studied the effects of including crop residues in alfalfa-grass haylage based rations on beef cow performance. Wheat straw or corn stalklage was included at 40% DM to the haylage based ration and compared to the control ration of 100% haylage. After being fed for 82 d, change in BCS between the 3 treatments was different ($P < 0.05$). Cows on the control ration had a positive change in BCS of 0.3, while wheat straw fed cows had a slight negative BCS change of -0.04 and corn stalklage cows had a negative BCS change of -0.3. These results suggest that crop residues such as wheat straw can be used in haylage based rations for wintering beef cows, however corn stalklage is not recommended.

Karn et al. (2005) studied the effects of cows rotationally grazed on swathed oat-pea and triticale crop residue and swathed drilled corn (RGSC; rotationally grazed swathed crops) compared to cows grazing swathed western wheatgrass (SWWG) and cows fed hay in a drylot pen. Body condition score tended to decrease for RGSC and SWWG cows in both years of the study. The average over 3 years showed that the SWWG cows had a slight decrease ($P < 0.15$) in BCS, while the other 2 treatments had increased body condition. The results from this study suggest that changes in BCS are comparable for cows swath grazing crop residues or western wheatgrass compared to cows fed baled hay in a drylot pen.

In the current study, differences ($P < 0.05$) were observed for calving rate and calf birth weight between the DL and OAT treatment cows, but not between ($P > 0.05$) cows managed in the DL and PEA or OAT and PEA treatments (Table 3.7). The effect of continued reduced nutritional intake may have an effect and cause a decrease in calf birth BW and lengthen gestation, which may represent a difference in conception date for the cows under nutritional stress (Larson et al. 2009). Evidence is available to support that low pre-calving energy levels can be detrimental to subsequent rebreeding because cows with a low BCS ($BCS < 2$) at calving

Table 3.7 Effect of winter feeding system on beef cow reproductive performance over 2 yr					
Item	Treatment ^z			SEM	P value
	DL	OAT	PEA		
Calving rate (%)	100a	91b	96ab	2.4	0.04
Calf birth weight (kg)	42a	38b	40ab	0.9	0.04
Calf birth date (Julian date)	113	117	112	3.0	0.49
First calf born (Julian date)	92	97	92	2.8	0.38
Last calf born (Julian date)	140	145	135	4.9	0.33
Length of the calving span (d)	47	49	43	5.3	0.75
Calving Pattern (% of total)					
1 to 21 d	48	34	56	8.2	0.20
22 to 42 d	36	43	30	7.8	0.53
43 to 63 d	16	23	14	6.4	0.59

^zDL = drylot cows fed grass-legume round bale hay; OAT = cows grazing oat residue in field paddocks; PEA = cows grazing pea residue in field paddocks

a-b Least squares means within a row and with different letters differ ($P < 0.05$)

SEM = standard error of the mean

will require a longer period to return to estrus (Dunn et al. 1969; Bellows and Short 1978). In the current study, cows did not lose enough body condition to explain the difference in reproductive performance between the OAT cows and DL cows. In fact cows in the current study started calving mid-April each year, 84 and 136 d after trial end in 2009-2010 and 2010-2011 respectively. No differences were observed between treatments for calf birth date ($P = 0.49$), date of first ($P = 0.38$) and last calf born ($P = 0.33$), length of calving span ($P = 0.75$) and calving pattern ($P = 0.20$; $P = 0.53$; $P = 0.59$; for 1 to 21 d, 22 to 42 d and 43 to 63 d, respectively). This is similar to the results of McCartney et al. (2004), who compared 3 winter feeding strategies including straw and barley silage fed daily, on alternating days and swath grazing whole-plant barley. Calf birth date, weight, date of first and last calf born, calving span, calving interval and calving pattern were similar between winter feeding strategies for the subsequent year (McCartney et al. 2004). Numerical differences were found for the calving pattern, with a lower percentage of the total cows calving in the first 21 d for the OAT cows. Cows that calve later will

return to estrus later and consequently conceive later, delaying calving the following year (Stevenson et al. 1997).

Larson et al. (2009) compared pregnant beef cow performance between grazing winter range (WR) with or without supplement and corn residue (CR) with or without supplement over a 3 year period. The authors reported no difference ($P > 0.05$) between treatments for pregnancy rate. However, calf birth weight was greater ($P = 0.02$) for cows on CR compared to cows on WR and tended to increase ($P = 0.11$) with supplementation. In contrast to this, earlier research did not find differences in calf birth BW due to supplementation of cows winter grazing using the same cowherd (Stalker et al. 2006; Martin et al. 2007). Non-supplemented cows grazing WR were also found to have a calving date 5 d later ($P = 0.01$) compared to all other treatments (Larson et al. 2009). Cows grazing winter range were found to be 42 kg lighter ($P < 0.001$) than those grazing corn residue, and of those cows grazing winter range, cows that did not receive supplement were 37 kg lighter ($P = 0.02$) than those that did receive supplement (Larson et al. 2009).

Anderson et al. (2005) conducted a 3 yr study evaluating animal performance between cows grazing pasture and crop residue and then fed hay (TRT) or cows in a control system, where animals grazed only pasture and were fed hay (CON). The authors reported that calving rates were similar for both groups (CON = 91%; TRT = 93%). Wood et al. (2010) found no difference ($P = 0.33$) in calf weaning weights between cows fed corn stalklage and haylage, and no differences ($P > 0.88$) between dietary treatments for calf birth weight. Cows fed wheat straw had greater ($P = 0.02$) calf weaning weights than cows fed corn stalklage, but no difference ($P = 0.23$) in calf weaning weight compared to cows fed haylage. The reason for the lower weaning weights of calves from the corn stalklage treatment may be because cows on this treatment had a

low DMI and a dietary energy deficiency prepartum, resulting in lower milk production postpartum (Wood et al. 2010). Similarly, Perry et al. (1991) found that calves had lower weaning weights when cows were fed an energy deficient diet for 100 d prepartum. The energy restricted cows had lower milk production than the high energy fed cows, even when fed the same ration postpartum (Perry et al. 1991).

3.3.4 Economic analysis

Costs associated with the study included feed and pasture costs, and yardage including labour, fuel, equipment use, infrastructure establishment, maintenance and depreciation. The variable costs include the feed costs, while the fixed costs include the yardage costs. Rolled oat grain was priced at \$120 per tonne for both years. Mineral and salt were purchased from FeedRite Ltd. (Humboldt, Saskatchewan, Canada) and mineral was priced at \$0.60 per lb in 2009 and \$0.57 per lb in 2010 and salt was priced at \$5.10 per block. In 2009, the value of crop residue was calculated by determining the crop production expenses and subtracting the crop revenue, which resulted in the crop residue having a low cost. Since no grain was combined in 2010, oat residue was valued at $\$0.44 \text{ cow}^{-1} \text{ d}^{-1}$, while pea residue was valued at $\$0.48 \text{ cow}^{-1} \text{ d}^{-1}$. Labour was valued at \$15.00 per hour (SMA 2006) and equipment rates were obtained from SMA (2006).

Average total costs in 2009 were \$2.77, \$1.01, and $\$1.22 \text{ cow}^{-1} \text{ d}^{-1}$ for DL, OAT, and PEA systems, respectively and in 2010 were \$1.84, \$1.26, and $\$1.37 \text{ cow}^{-1} \text{ d}^{-1}$ for DL, OAT, and PEA systems, respectively (Table 3.8). Total yardage costs including machinery, infrastructure and labour were $\$0.32 \text{ cow}^{-1} \text{ d}^{-1}$ for both OAT and PEA systems compared to $\$0.46 \text{ cow}^{-1} \text{ d}^{-1}$ for the DL system. The average costs over both years show a 47% decrease in costs for the OAT

compared to the DL system and a 39% decrease in costs for the PEA compared to the DL system. Although the PEA system costs were less than the DL system costs, the cows grazing pea residue had negative changes in BW, rib fat and rump fat and body condition score.

Table 3.8 Economics of winter feeding systems

Item	Treatment ^z					
	DL		OAT		PEA	
	2009	2010	2009	2010	2009	2010
Feed costs (\$ cow ⁻¹ d ⁻¹)						
Forage	2.13	1.19	0.20	0.44	0.31	0.48
Supplemented hay	-	-	-	0.25	-	0.27
Oat grain	0.04	-	0.32	0.18	0.41	0.22
Canola meal	-	-	0.02	-	-	-
DDGS	-	-	0.03	0.07	0.06	0.07
Mineral & salt	0.10	0.13	0.12	0.11	0.12	0.15
Bedding	0.04	0.06	-	0.07	-	0.08
Total feed costs	2.31	1.38	0.69	1.12	0.90	1.27
Yardage costs (\$ cow ⁻¹ d ⁻¹)						
Machinery, Infrastructure	0.29	0.29	0.16	0.16	0.16	0.16
Labour	0.17	0.17	0.16	0.16	0.16	0.16
Total yardage costs	0.46	0.46	0.32	0.32	0.32	0.32
Total production costs (\$ cow ⁻¹ d ⁻¹)	2.77	1.84	1.01	1.44	1.22	1.59
Average total production costs	2.31		1.23		1.41	

^zDL = drylot cows fed grass-legume round bale hay; OAT = cows grazing oat residue in field paddocks; PEA = cows grazing pea residue in field paddocks

Although feed costs in the current study are lower for both extensive grazing treatments, it is important to consider the cost and availability of supplements that need to be provided to animals in field grazing. It is also important to remember that costs for replicated experimental trials may be more expensive due to intensive data collection and managing animals in multiple replicate groups. Van De Kerckhove (2010) compared cows grazing barley crop residue and supplemented with either 100% wheat-corn blend DDGS, 50:50 DDGS and barley grain, or

100% barley grain and found that average total costs were similar (\$0.77 to \$0.78 cow⁻¹ d⁻¹) for the 3 supplement strategies when data were pooled over 2 years. Supplement price may cause variation in the annual cost of an extensive grazing system and producers need to choose cost effective supplements based on current market value. Van De Kerckhove et al. (2011) found that cows supplemented with 100% DDGS had positive BW change ($P < 0.01$) compared to cows supplemented with barley grain.

Kelln et al. (2011) found that winter feeding system costs averaged \$0.98, \$0.76, \$1.27, and \$1.07 cow⁻¹ d⁻¹ for bale grazing, swath grazing, straw-chaff grazing, and drylot feeding over 3 years. Costs for residue grazing were high because supplement cost in this system was \$0.72 per d, while other systems did not require any supplement. The supplement used in the study was a Feed Rite range pellet, which was more expensive relative to barley in both years of the study. The average cost of supplementation could have been decreased by choosing a more economical source of supplementation.

McCartney et al. (2004) found feed costs to be lower ($P < 0.01$) for swath grazing cows compared to cows fed straw and barley silage every day (traditional), or fed straw and barley silage every other day (alternate day) at \$0.62, \$0.91 and \$0.88 cow⁻¹ d⁻¹, respectively. The cost for the first 100 d of winter feeding for the swath grazing winter feeding strategy was \$70.00 and \$56.70 cow⁻¹ less than the traditional or alternate day winter feeding strategies, respectively. With the addition of yardage costs, total costs were \$0.83, \$1.54 and \$1.40 cow⁻¹ d⁻¹ for swath grazing, traditional and alternate day feeding strategies, respectively. Swath grazing required 21 and 38% less labour than alternate day or traditional feeding, respectively, although labour for bedding and the amount of bedding used in the swath grazing treatment was greater than the

other treatments. This was caused because establishing a bedding pack in a field requires more bedding than to bed a small drylot pen.

3.4 Conclusion

The opportunity exists to utilize crop residues in winter grazing systems beef cows, however environmental and growing conditions will vary considerably from year to year. This variability can impact crop seeding time, residue yield and quality. Crop residues are a tremendous untapped resource and if supplemented appropriately and grazed in favourable winter conditions, can provide an economical source of nutrition for pregnant beef cows. However, it is important to feed test crop residues for nutritive value in order to develop a ration and provide adequate supplement to meet the pregnant cow's nutritional requirements. Energy and protein have both been found to be limiting when grazing crop residues because of their lower quality.

In the current study, DMI was lower ($P < 0.01$) for cows grazing oat residue in field compared to cows fed baled hay in drylot pens, while cows grazing pea residue in field had lower ($P < 0.01$) DMI than both the oat residue grazing and drylot fed cows. This may be a reflection of higher NDF content and poorer palatability of oat or pea residues combined with adverse winter weather conditions altering DMI in the field. As a result, cow performance on both crop residue grazing systems was affected compared to cows managed in the drylot treatment including cow BW change, rib and rump fat and body condition score. Cows grazing pea residue were found to have lower ($P < 0.01$) cow BW change, rib and rump fat and BCS than cows fed hay in drylot pens. Calf birth BW and calving rate were both lower ($P = 0.05$) for OAT cows compared to DL cows for the average of both years. The 2 yr length of this study was not

long enough to determine whether the winter feeding systems had a prolonged effect on differences in cow reproductive performance.

A 39 to 47% reduced total cost was calculated for both the crop residue grazing systems compared to drylot feeding. However, even though an extensive system involving grazing crop residue can have lower costs than drylot feeding, this does not necessarily mean that grazing crop residue is the best option for winter feeding. Supplement cost and availability will vary from year to year and can impact whether grazing crop residues will be economical. In addition, the amount of supplement required to meet the animal's nutritional requirements will also affect overall costs for grazing crop residues.

Finally, cows grazing oat crop residue in field paddocks and supplemented with oat grain appeared to maintain BW, rib and rump fat and BCS, while cows grazing pea crop residue experienced a slight decrease in BW, rib and rump fat and body condition score. Differences in animal DMI and performance between 2009 and 2010 shows how variations in weather conditions and feed quality can create challenges in managing winter feeding systems.

4.0 *In situ* degradability of protein, fiber and dry matter of three different forages

4.1 Introduction

The grazing season for beef cows can be extended with the use of low quality crop residues from annual crops. However, residues can be low in crude protein and high in fiber (NRC 2000), which can limit rumen degradability (McCartney et al. 2006). Degradability will vary depending on leaf to stem ratios in straw, but generally chaff and the leaf components have a higher level of degradation than stems (Kernan et al. 1984; Ramanzin et al. 1986; Shand et al. 1988; Thomson et al. 1993).

When low quality forages are grazed, supplementation is often required to meet the animal's protein and energy requirements. Increased rate of forage digestion is often associated with increased forage intake (McCollum and Galyean 1985; Mathis et al. 1999). Protein supplementation has been shown to have positive effects on forage intake (DelCurto et al. 1990b) supporting microbial growth, which improves rumen fermentation and forage digestion (Siebert and Hunter 1982). Efficient microbial digestion in the rumen is important for forage utilization, since cell-wall components (cellulose and hemi-cellulose) are the most important components of cereal straw (Bruno-Soares et al. 2000). To maximize the utilization of low quality forages, rumen conditions must be favourable for cellulolytic bacteria which are the main organisms responsible for forage digestion (Hiltner and Dehority 1983). Ideal rumen pH for cellulolytic bacteria to thrive is between 6.3 and 6.8 (Hiltner and Dehority 1983; Hoover 1986), while a pH below 6.0, cellulolytic bacteria are inhibited (Mould and Ørskov 1983; Mould et al. 1983).

Digestibility refers to the nutrient fraction that is degraded and retained in the digestive tract after ingestion of a feedstuff (Cochran and Galyean 1994; Kitessa et al. 1999). There are

several techniques to determine the digestibility of different feeds for beef cattle. These techniques include *in vivo*, *in situ* and *in vitro*. *In vivo* and *in situ* techniques both require ruminally cannulated animals and can be expensive (Adesogan et al. 2000). The nylon bag technique is an example of an *in situ* technique, where samples of feed are incubated in the rumen (Huntington and Givens 1995). This technique provides information on rumen digestion kinetics and digestion at different time periods (Fonseca et al. 1998). *In vitro* techniques are performed in a laboratory and simulate rumen fermentation (Adesogan et al. 2000).

Forage degradation refers to how completely a forage is broken down by rumen bacteria and fractionated into three levels of degradation: 1) immediately soluble (S); 2) potentially degradable (D); and 3) undegradable (U) (Orskov and McDonald 1979; Robinson et al. 1986). Several studies have suggested that degradation characteristics of low quality forages provide a useful basis for the evaluation of their nutritive value (Orskov et al. 1988; Shem et al. 1995; Bruno-Soares et al. 2000). Information is limited regarding rumen degradation characteristics of oat residue and pea residue in comparison to mixed grass-legume hay. Therefore, the objectives of this study were (i) to assess the nutritive value of grass-legume hay, oat residue and pea residue sampled at start and end of trial; (ii) to assess rumen degradation kinetics of dry matter (DM), crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) for grass-legume hay, oat residue and pea residue sampled at 2 calendar dates during a grazing trial.

4.2 Materials and methods

4.2.1 Collection of forages

A 2 year winter grazing study was conducted at the Western Beef Development Centre's Termuende Research Ranch near Lanigan, Saskatchewan, Canada (51°51 'N, 105°02 'W). Sixteen ha each of pea (cv. Performance 40-10) and oat (cv. Baler) were seeded on May 28, 2009 and July 13, 2010. In 2009, pea and oat crops were swathed on September 18 and November 3, respectively and combined on September 23 and November 5, respectively. In 2010, both crops were swathed and combined on October 15 and October 16, respectively. Straw-chaff residues were collected in piles using a whole-buncher (AJ Manufacturing, Calgary, Alberta, Canada) attached to the combine and deposited in the field. Ten representative samples of oat and pea residue from each of 3 replicate paddocks were collected at the start and end of a grazing trial in 2009 and 2010. In addition, representative samples of mixed grass-legume hay was also collected from each of 3 replicate pens at the start of trial in 2009.

4.2.2 Animals, housing and diet

Three ruminally cannulated, dry Holstein cows with an average age of 6 years, were used for the experiment. During the experimental period, cows were fed a silage based total mixed ration (TMR) with the diet composition as follows, 22 kg barley silage (33.4% DM; 12.3% CP; 32.1% ADF; 49.9% NDF; 63.0% TDN), 7 kg chopped alfalfa hay (84.3% DM; 18.9% CP; 31.7% ADF; 41.8% NDF; 58.5% TDN) and 1 kg energy supplement (DAC-485). Ingredients of DAC-485 were ground barley (55%), corn distiller's grains with solubles (10%), canola meal (10%), soybean meal (10%), UofS dairy premix (3%), Mono-Ca Phosphate (3%), Co-op cobalt iodized salt (2.5%), mill mix 60/40 (2.5%), limestone (2%), canola oil (1%), niacin (B3) (0.6%),

Rovimix E50 LT (0.2%), Vit A 1000 LT (0.005%) and Rovimix D500 LT (0.002%). Cows were housed in tie-stalls at the University of Saskatchewan campus dairy barn. Animals used in the experiment were cared for in accordance with the guidelines of the Canadian Council on Animal Care (1993).

4.2.3 *In situ* procedures and laboratory analysis

All dried hay, oat and pea residue samples were ground to pass through a 2-mm screen in a Wiley mill (Philadelphia, PA). Ruminal degradation characteristics were determined using the standard *in situ* procedure as described by Yu et al. (2003; 2004). The procedure involved weighing 7 g of each forage sample into number-coded Dacron nylon bags (10 cm x 20 cm; 40 ± 10 μ m pore size) with all bags tied about 2 cm below the top, allowing a ratio of 28 mg per cm² of sample size to bag surface area. Bags were placed in a mesh laundry bag before they were inserted into the rumen. The rumen incubations were performed according to the “gradual addition/all out” schedule (bags are inserted sequentially and retrieved at the same time) according to Yu et al. (2004). Samples were incubated in the ventral rumen for 72, 48, 24, 12, 8, 4, 2 and 0 h. Incubation was repeated for a total of 3 runs for statistical purposes (Table 4.1).

Table 4.1 presents a summary of the experimental procedure for *in situ* incubation.

Table 4.1 Summary of experimental procedure for <i>in situ</i> incubation			
	Treatments		
	Grass-legume hay	Oat residue	Pea residue
Years	1	2	2
Sampling dates	SOT	SOT, EOT	SOT, EOT
Total Treatments	1	4	4
Runs	3	3	3
Incubation times (h)	0, 2, 4, 8, 12, 24, 48, 72	0, 2, 4, 8, 12, 24, 48, 72	0, 2, 4, 8, 12, 24, 48, 72
Bags required	66 (22 per run)	264 (22 per run)	264 (22 per run)

After incubation, all bags were removed from the rumen and rinsed in cold water to remove excess ruminal contents and to stop further microbial activity. The bags were then washed with cool water without detergent by hand 6 times with 6 bags each round. A separate set of bags were prepared and rinsed under the same conditions without ruminal incubation (0 h). After rinsing, the sample residues were dried to a constant weight at 55°C for 48 h. Weights were recorded for bag + string + residue.

Prior to lab analysis, forage samples were dried at 55°C for 48 h and ground to pass through a 1-mm screen with a Retsch ZM-1 grinder (Haan, Germany). Forage samples were analyzed for moisture, ash, crude protein (CP), ether extract (EE), acid detergent fiber (ADF), neutral detergent fiber (NDF), acid detergent lignin (ADL) and acid detergent insoluble nitrogen (ADIN). Total digestible nutrients (TDN) (% DM) were calculated for forage samples using the Weiss et al. (1992) equation. Calcium (Ca) and phosphorus (P) were analyzed by Central Testing Laboratory Ltd. (Winnipeg, Manitoba, Canada).

Moisture and ash were determined according to the procedures outlined by the Association of Official Analytical Chemists (method #930.15; AOAC 2000). Crude protein (N x 6.25) and ADIN concentrations were determined using the Kjeldahl procedure (method #984.13; AOAC 2000) using the 2400 53 Kjeltac Analyzer Unit (FOSS Tecator, Hoganas, Sweden). Neutral detergent fiber and ADF (method #973.18; AOAC 2000) were analyzed according to the Labconco procedure. Acid detergent lignin content was evaluated using the beaker method outlined by ANKOM Technology (method # 973.18; AOAC 2000). Ether extract was determined according to the procedure outlined by the AOAC (method #920.39; AOAC 2000).

Sample residues were pooled according to treatment and incubation time and then ground with a coffee grinder to 1 mm for chemical analysis of residual DM, CP, NDF and acid detergent

fibre. Dry matter was analyzed by drying samples at 100°C for 5 h (AOAC 2000; method 930.15). Crude protein was analyzed for N content using a combustion N analyzer (Leco FP-528, Leco Corporation, St. Joseph MI). Neutral detergent fiber and ADF were analyzed for using an ANKOM 2000 Fiber Analyzer (ANKOM Technology, Fairport, NY).

4.2.4 Statistical analysis

Orskov and McDonald (1979) created the first-order kinetic degradation model used to describe the rumen degradation characteristics of DM and CP. The model is solved with the use of the NLIN procedure of SAS (SAS Institute Inc. 2009) using least squares regression and the following equation:

$$\text{Equation 4.1} \quad R(t) = U + (-S - U) \times e^{(-K_d \times (t - T_0))}$$

where $R(t)$ = residue present (%) at t hours of incubation; U = undegradable fraction (%); S = soluble fraction (%); K_d = degradation rate (%/h); and T_0 = lag time (h).

Effective degradability (ED) of DM, CP, NDF, and ADF was determined using the nonlinear (NLIN) parameters calculated by the above equation (S , U , D , and K_d):

$$\text{Equation 4.2} \quad ED \text{ (g kg}^{-1}\text{)} = S + D \times K_d / (K_p + K_d)$$

where S = soluble fraction (%) as determined by the samples incubated for 0 h and K_p = rate of passage (4.0% h⁻¹; Yu et al. 2004).

Statistical analyses were performed using the MIXED procedure of SAS (SAS Institute Inc. 2009). The model used for the analysis was $Y_{ij} = \mu + F_i + e_{ij}$, where Y_{ij} is an observation of the dependent variable ij ; μ is the population for the variable; F_i is the effect of feed sources, as a fixed effect; batch and runs as replications, and e_{ij} was the random error associated with the observation ij . For all statistical analyses, significance was declared at $P < 0.05$.

4.3 Results and discussion

Nutritive value of hay, oat residue and pea residue sampled at different times and averaged over 2 years are presented in Table 4.2. Total digestible nutrient values calculated using the Weiss equation (Weiss et al. 1992) were 64.0, 60.6, 62.1, 55.1 and 55.0% of DM for mixed hay, oat residue SOT, oat residue EOT, pea residue SOT and pea residue EOT, respectively. Residue lignin values in 2009 were considered unreliable due to laboratory problems in 2009 with the lignin analysis method. Lignin values from 2010 were used to calculate TDN for oat and pea residue in 2009 using the Weiss equation (Weiss et al. 1992). Crude protein values were 55 and 51% lower for oat residue than for mixed hay or pea residue, respectively. Neutral detergent fiber was 25 and 17% lower for mixed hay compared to oat residue and pea residue, respectively. Acid detergent fiber was 30 and 42% lower for mixed hay compared to oat residue and pea residue, respectively.

Table 4.2 Nutritive value of forages sampled at different times and averaged over 2 yrs

Nutrient	Mixed hay	Oat residue		Pea residue	
		SOT	EOT	SOT	EOT
CP (% DM)	9.1	4.3	3.8	8.3	8.4
NDF (% DM)	50.8	66.2	68.7	60.7	61.6
ADF (% DM)	27.3	38.6	39.2	47.5	45.9
ADL (% DM) ^z	8.7	3.0	3.0	8.8	9.5
EE (% DM)	1.4	1.5	1.8	1.5	1.2
Calcium (% DM)	0.8	0.2	0.4	1.1	1.1
Phosphorus (% DM)	0.1	0.2	0.2	0.2	0.2
ADIN (% DM)	7.6	16.3	20.8	25.3	25.8
TDN (% DM)	64.0	60.6	62.1	55.1	55.0

^zADL = lignin values from 2010 only

The effect of forage type (grass-legume hay, oat residue and pea residue) on rumen fractions (S, D, U), rate of degradation (K_d), and effective degradability (ED) are presented in Table 4.3 for 2009 and 2010 pooled data. Rate of degradation (K_d) of DM was greater ($P < 0.01$) for PEA EOT compared to HAY, OAT SOT and OAT EOT with differences of 31, 45 and 50%, respectively (Table 4.3). Dry matter rate of degradation for PEA SOT was greater ($P < 0.05$) compared to OAT SOT and OAT EOT with differences of 38 and 45%, respectively. The effectively degradable fraction of CP was greater ($P = 0.03$) for HAY compared to PEA EOT with a difference of 44 percent (Table 4.3). The ruminally undegradable fraction of CP was greater ($P = 0.03$) for PEA EOT compared to HAY with a difference of 37 percent. This may suggest that although the CP level in the pea residue was high enough to meet the cows' nutrient requirements, the protein source was probably low in degradable intake protein. The low effectively degradable fraction of CP for the pea residue may also help explain the low DMI in the pea residue grazing cows because the low effectively degradable fraction represents poor fiber digestion and rumen function. Yu et al. (2004) suggests that effective degradability is a function of the total degradable fraction, rate of degradation and passage rate.

Acid detergent fiber rate of degradation (K_d) was greater ($P = 0.01$) for PEA EOT compared to HAY, OAT SOT and OAT EOT with differences of 29, 41 and 46%, respectively (Table 4.3). Acid detergent fiber rate of degradation for PEA SOT was greater ($P < 0.05$) compared to OAT SOT and OAT EOT with differences of 37 and 42%, respectively. No differences ($P > 0.05$) were observed between either OAT SOT and OAT EOT or PEA SOT and PEA EOT for S, D, U, ED or RU suggesting that weathering did not have an effect on the degradability of the forages.

Table 4.3 *In situ* rumen degradation kinetics of three forages (grass-legume hay, oat residue and pea residue) collected at start and end of study over 2 years

Item ^y	Treatment ^z					SEM	P-value
	Hay	Oat SOT	Oat EOT	Pea SOT	Pea EOT		
Dry matter							
K _d (% h ⁻¹)	5.72bc	4.57c	4.12c	7.43ab	8.24a	0.445	< 0.01
S (%)	17.08	23.11	18.00	18.73	18.91	8.817	0.99
D (%)	41.03	48.26	53.02	32.15	29.79	6.186	0.14
U (%)	41.89	28.63	28.98	49.12	51.30	12.966	0.62
Effectively degradable DM (%)	37.09	43.91	39.61	36.63	36.27	11.396	0.99
Ruminally undegradable DM (%)	62.91	56.09	60.39	63.37	63.73	11.396	0.99
Crude protein							
K _d (% h ⁻¹)	7.35	5.96	7.08	7.21	7.08	1.997	0.99
S (%)	32.19	24.33	17.78	16.89	11.71	9.004	0.49
D (%)	46.68	49.84	56.92	34.76	35.36	14.197	0.77
U (%)	21.14	25.84	25.30	48.35	52.93	7.070	0.06
Effectively degradable CP (%)	57.62a	46.09ab	41.09ab	36.43ab	32.37b	4.491	0.03
Ruminally undegradable CP (%)	42.38b	53.91ab	58.91ab	63.57ab	67.63a	4.491	0.03
Neutral detergent fiber							
K _d (% h ⁻¹)	4.92	4.82	4.33	5.71	6.24	0.709	0.41
S (%)	0.31	5.89	1.59	2.43	6.00	3.632	0.69
D (%)	45.41	62.61	67.61	38.19	33.99	8.750	0.12
U (%)	54.28	31.50	30.81	59.38	60.01	8.491	0.10
Effectively degradable NDF (%)	20.76	33.92	30.01	21.17	23.75	5.282	0.36
Ruminally undegradable NDF (%)	79.24	66.08	69.99	78.83	76.25	5.282	0.36
Acid detergent fiber							
K _d (% h ⁻¹)	5.62bc	4.67c	4.29c	7.44ab	7.91a	0.472	0.01
S (%)	0.49	1.35	2.26	0.45	0.50	1.042	0.67
D (%)	47.13	63.85	64.95	39.03	36.14	10.386	0.26
U (%)	52.37	34.80	32.80	60.53	63.36	11.159	0.28
Effectively degradable ADF (%)	23.27	29.52	29.33	22.30	21.24	6.616	0.82
Ruminally undegradable ADF (%)	76.73	70.48	70.67	77.70	78.76	6.616	0.82

^zTreatment: Oat SOT = oat residue start of trial; Oat EOT = oat residue end of trial; Pea SOT = pea residue start of trial; Pea EOT = pea residue end of trial

^yItem: K_d = rate of degradation; S = soluble fraction; D = potentially degradable fraction; U = undegradable fraction; EDDM = effectively degradable dry matter; RUDM = ruminally undegradable dry matter

SEM = pooled standard error of mean

a-c Means with different letters in the same row indicate significant differences (P < 0.05)

Literature evaluating degradability of oat residue is limited, but some papers have evaluated barley straw. Mathison et al. (1999) studied various factors that influence chemical composition and ruminal degradability of straw from several barley genotypes. Differences in ruminal degradability of straw between different barley genotypes were found (Mathison et al. 1999) and were confirmed by other studies (Tuah et al. 1986; Shand et al. 1988; Ørskov et al. 1990). Mathison et al. (1999) found that straw from two-row barley genotypes was 6% more digestible than straw from six-row genotypes and straw from semi-dwarf genotypes was 9% more digestible than straw from taller genotypes. Straw from barley genotypes with rough awns had lower rates of degradation and more of the slowly degraded fraction than straw with smooth awns (Mathison et al. 1999). Differences in nutritive value and ruminal degradability may suggest that it is possible to select genotypes most suitable for feeding without reducing the grain yield (Mathison et al. 1999; Tuah et al. 1986).

Forage digestibility often decreases with energy supplementation in low-quality, forage-based diets (Caton and Dhuyvetter 1997), and forage digestibility often increases with degradable intake protein supplementation in low-quality, forage-based diets (Köster et al., 1996; Bodine et al., 2000; Bandyk et al., 2001). Reed et al. (2004) evaluated the effects of field pea supplementation level on intake, digestion, ruminal fermentation and *in situ* digestibility in beef steers. Reed et al. (2004) found no differences in disappearance rate of *in situ* forage DM ($P = 0.32$), NDF ($P = 0.52$), or CP ($P = 0.12$) when the amount of supplemental field peas was increased. Reed et al. (2007) evaluated the effects of undegradable intake protein (UIP) supplementation level on intake, digestion, and *in situ* digestibility in beef steers fed low-quality grass hay and found that supplemental protein had no effect on *in situ* forage NDF ($P = 0.13$) or CP ($P = 0.21$) degradation. Field peas have lower starch and higher degradable intake protein,

which may be why their supplementation does not decrease forage digestion (Reed et al. 2004). Similarly, Krysl et al. (1989) found no differences for *in situ* disappearance of forage NDF with soybean meal and sorghum supplementation.

The soluble (S), potentially degradable (D) and undegradable (U) fractions of DM, CP, NDF and ADF were not different ($P > 0.05$) between forages in the current study (Table 4.3). The effectively degradable (ED) and ruminally undegradable (RU) fractions of DM, NDF and ADF were not different ($P > 0.05$) between forages. The numeric data may suggest that the potential degradability of DM, CP, NDF and ADF is lower for pea residue compared to oat residue and mixed grass-legume hay. This may help explain the results from the current field study where cows grazing pea residue in field paddocks had greater loss of BW, rib fat and rump fat compared to the cows grazing oat residue or cows fed hay in drylot pens. Cows grazing pea residue also had lower DMI than did cows grazing oat residue or fed hay in drylot pens. Allen (1996) also suggested that DMI is limited for low digestibility feeds because of physical distention in the gastrointestinal tract.

Scarborough et al. (2002) studied the effects of summer management and fall harvest date on ruminal *in situ* CP degradation of stockpiled bermudagrass. Ruminal availability of CP in stockpiled bermudagrass was found to decrease as the forage matured. However, forage CP content was 100 g kg^{-1} and was determined to be adequate to meet the minimum CP requirements of dry, pregnant beef cows (Scarborough et al. 2002).

Flachowsky et al. (1991) studied the proportions of botanical fractions and *in situ* degradability of 6 different cereals (oats, spring barley, winter barley, winter rye, winter wheat and triticale). *In situ* degradability of nodes and internodes was lower than leaves or chaff and degradability of straw was influenced by the proportion of the different fractions (Flachowsky et

al. 1991). As a cereal crop matures, the proportion of nodes and internodes increases, making the forage less degradable with maturity (Ramanzin et al. 1986; McCartney et al. 2006).

Varel and Kreikemeier (1999) studied the effect of cow age on apparent forage utilization and degradability. *In situ* NDF degradation rate was 3 and 0.5% h⁻¹ greater ($P < 0.01$) in mature cows compared to heifers when alfalfa and brome hays were fed, respectively. Ruminal digestibility of NDF as a percentage of DMI was also greater ($P < 0.01$) for cows than for heifers (Varel and Kreikemeier 1999). These results help explain how low quality forages may not be suitable for immature cattle since they have lower degradation rates and will not be able to consume enough forage to meet requirements (Hutton et al. 2008).

4.4 Conclusion

In situ study results showed that pea residue has equal and greater rumen dry matter degradability than hay. Based on these results, it can be suggested that nutrient availability of oat residue and pea residue may be equal to or greater than hay provided. The soluble, potentially degradable and undegradable fractions of DM, CP, NDF and ADF were not different between forages. The effectively degradable and ruminally undegradable fractions of DM, NDF and ADF were not different between forages. Degradability of oat and pea residue collected at the start and end of trial were similar indicating little change in the chemical composition of forage due to weathering. These results suggest that low quality crop residues including oat and pea residue can be used to extend the grazing season for beef cows without reducing nutrient availability.

5.0 General discussion and conclusion

Low quality forages have been used in winter feeding systems for beef cows in order to reduce feed costs. Since low quality forages are low in both energy and protein it is important to provide adequate supplementation in order to meet the animal's nutritional requirements. The objective of this study was to determine the effect of field grazing either oat residue or pea residue or drylot feeding mixed hay on beef cow performance and reproductive efficiency. Nutritive value of oat residue, pea residue and grass-legume hay were evaluated to determine if these feeds could provide adequate nutrients for mature pregnant beef cows with minimal supplementation. Dry matter intake of crop residues and grass-legume hay were determined and each wintering system was evaluated for costs. *In situ* rumen degradation characteristics (DM, CP, NDF and ADF) were determined for oat residue, pea residue and mixed grass-legume hay.

In the first study, 3 winter feeding systems were evaluated including cows field grazing oat or pea residue or drylot fed mixed grass-legume hay. Cows grazing pea residue had lower ($P < 0.01$) DMI than cows grazing oat residue or fed hay in drylot pens. Cows grazing oat residue had lower ($P < 0.01$) DMI than cows fed hay in drylot pens. This may be related to the higher NDF content and poor palatability of oat and pea residues in addition to winter weather conditions. As a result, cow performance on both residue grazing systems was affected when compared to cows fed hay in drylot pens including cow BW change, rib and rump fat and body condition score. Cows grazing pea residue were found to have lower ($P < 0.01$) cow BW change, rib and rump fat and BCS than cows fed hay in drylot pens. Calf birth BW and calving rate were both lower ($P = 0.05$) for cows grazing oat residue compared to cows fed hay in drylot pens for the average of both years. The 2 yr length of this study was not long enough to determine

whether the winter feeding systems had an effect on these differences in reproductive performance.

The total cost for the residue grazing systems was calculated to be 39-47% lower than the drylot pen feeding system. Forage and yardage costs were both lower for the residue grazing systems than for the drylot pen feeding system. However, this does not necessarily mean that grazing crop residue is the best option for winter feeding. The cost of residue grazing will vary from year to year depending on the crop revenue, supplement costs and the amount of supplement required to meet the animal's nutritional requirements. Yardage costs including machinery and labour will also have an impact on whether grazing residues will be economical.

In situ study results showed that degradability of oat and pea residue collected at the start and end of a field grazing trial were similar indicating little change in the chemical composition of forage due to weathering. Pea residue was found to have equal and greater rumen dry matter degradability than hay. The effectively degradable fraction of CP was lower for pea residue compared to hay suggesting that the CP in pea residue is a poor source. The numeric data may suggest that the potential degradability of DM, CP, NDF and ADF is lower for pea residue compared to oat residue and mixed grass-legume hay. This may help explain the results from the current field study where cows grazing pea residue in field paddocks had greater loss of BW, rib fat and rump fat compared to the cows grazing oat residue or cows fed hay in drylot pens. Cows grazing pea residue also had lower DMI than did cows grazing oat residue or fed hay in drylot pens. Allen (1996) also suggested that DMI is limited for low digestibility feeds because of physical distention in the gastrointestinal tract. Based on these results, nutrient availability of oat residue and pea residue may be equal to or greater than hay provided.

The opportunity exists to utilize crop residues in winter diets for grazing beef cows, however environmental and growing conditions will vary considerably from year to year. This variability can impact crop seeding time, residue yield and nutritive value. These annual variations will make it necessary to have an alternative plan to manage and feed cows during the winter if residue grazing is not feasible. Crop residues are a tremendous untapped resource and if supplemented appropriately and grazed in favourable winter conditions, can provide an economical source of nutrition for pregnant beef cows. However, it is important to feed test crop residues for nutritional composition in order to develop a ration and provide adequate supplement to meet the animal's nutritional requirements. Energy and protein have both been found to be limiting when grazing crop residues because of their lower nutritive value.

Cows grazing oat residue in field paddocks and supplemented with oat grain appeared to maintain BW, rib and rump fat and BCS, while cows grazing pea crop residue experienced a slight decrease in BW, rib and rump fat and body condition score. Differences in animal DMI and performance between 2009-2010 and 2010-2011 shows how variations in weather conditions and feed quality can create challenges in managing winter feeding systems. From the results of this study over 2 years, it can be suggested that grazing cows on crop residues may be an economical alternative to traditional drylot pen wintering systems. Crop residues may provide sufficient nutrients to meet the animal's requirements with minimal supplementation. Cold temperatures and heavy snowfall may impact accessibility to residues and cow performance. Economic benefits to winter grazing systems may outweigh the risks making crop residue grazing a viable alternative to drylot pen feeding during the winter months in Western Canada.

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APPENDIX A

Table A.1 Average daily meteorological data for Termuende Research Ranch^z

Month	Temperature (°C)			Precipitation (mm)		
	Maximum	Minimum	Mean	Rain	Snow	Total
June 2009	21.7	8.2	14.9	85.6	0	85.6
July 2009	21.2	9.4	15.3	78	0	78
August 2009	21.7	8.4	15.0	62	0	62
September 2009	23.7	6.7	15.2	45	0	45
October 2009	4.9	-2.6	1.1	14	14.8	28.8
November 2009	6.5	-7.2	-0.4	0	1	1
December 2009	-13.9	-23.5	-18.7	0	8.8	8.8
January 2010	-8.8	-17.6	-13.2	0	31	31
February 2010	-9.9	-20.3	-15.1	0	6.5	6.5
March 2010	2.0	-7.7	-2.9	0	0	0
April 2010	12.4	-1.1	5.7	95	0	95
May 2010	14.8	3.1	9.0	123	4	127
June 2010	20.9	10.5	15.7	161.4	0	161.4
July 2010	23.6	12.0	17.8	61.2	0	61.2
August 2010	22.3	10.3	16.3	67.2	0	67.2
September 2010	17.0	3.6	10.3	119	0	119
October 2010	13.2	-0.4	6.4	12	23	35
November 2010	-4.6	-12.2	-8.6	0	30.2	30.2

^zMeteorological data from Environment Canada's Climate Data Online (www.climate.weatheroffice.ec.gc.ca) for Watrous and Esk, Saskatchewan